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# SANITARY ENGINEERING.

# SANITARY ENGINEERING;

## A GUIDE

TO THE CONSTRUCTION OF

# WORKS OF SEWERAGE

AND

# HOUSE DRAINAGE;

WITH

TABLES FOR FACILITATING THE CALCULATIONS OF THE ENGINEER.

BY

BALDWIN LATHAM, C.E., M. Inst. C.E.

PAST PRESIDENT OF THE SOCIETY OF ENGINEERS, &c.

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# PREFACE.

## ERRATA.

Page 31, line 20 from top, *for* "side" *read* "site."
„ 93, line 4 from bottom, *insert* comma *after* "outfall."
„ 113, line 10 from top, *omit words* "or smaller."
„ 147, line 15 from bottom, *omit* comma *after* "barrel."
„ 199, line 5 from top, *for* "sewre" *read* "sewer."
„ 233, line 8 from bottom, *for* "objections" *read* "objection."
„ „ line 7 from bottom, *for* "are" *read* "is."
„ 246, line 5 from top, *for* "is" *read* "are."
„ 291, line 17 from top, *for* "advantages consist" *read* "advantage consists."
„ 292, line 12 from top, *for* "alteration" *read* "illustration."
„ 339, line 9 from bottom, *for* "clean" *read* "clear."

B. L.

7, Westminster Chambers,
London, S.W., April, 1873.

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# PREFACE.

It should now be well known that the preservation of life and health is in a great measure dependent on the faithful prosecution of sanitary works. On this account the information contained in this volume is made public, for, important as the study of Sanitary Science may appear, nevertheless, up to the present time, no work has been published which treats entirely on subjects relating to sanitary engineering. The literature of sanitary engineers is, for the most part, spread over a vast number of Parliamentary papers. The present volume, treating entirely upon works of Sewerage and House Drainage, is offered as an instalment, to be followed by other volumes, so as to complete the whole range of the works in which the Sanitary Engineer is engaged. In compiling this volume, the author has not confined himself to examples taken exclusively from his own practice, but has given examples and opinions of other professional men, who are labouring in the same field with him, in prosecuting works for the welfare of humanity. The author is conscious that many imperfections exist in this volume, but his great anxiety has been to make the information it contains public as speedily as possible, and his excuse for not having presented it in better form must be that it has been hurriedly compiled in the moments of leisure snatched from active professional pursuits.

B. L.

7, Westminster Chambers,
London, S.W., April, 1873.

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# SANITARY ENGINEERING.

## INTRODUCTION.

### NECESSITY OF SANITARY MEASURES.

Important to study animal physiology.

To those who have carefully studied the physiology of animal life it will be clear that life and health depend upon rightly understanding and practising those laws which constitute sanitary science.

Agents promoting life and health.

Use of agents destroys their vitality.

Pure air, pure water, and nutritious food, are the three great agents for promoting life and health. Any one of these once used, or combining with matter of a known deleterious character, loses its vital property, and becomes, as it were, poison, unfit again to fulfil its sanitary mission, until it has been exposed to those revivifying influences which will restore its vital energy.

Composition of the atmosphere.

Quantity of air and oxygen inspired.

Pure atmospheric air consists of oxygen, nitrogen, and a small quantity of carbonic acid, and is inspired by the human subject at the rate of about 57 hogsheads every twenty-four hours; the oxygen contained therein (amounting to from 30 to 40 ounces) combines in the lungs with the elements of the blood, and, so long as life exists, the air and blood are continually flowing towards each other in the proportion of about 18 volumes of air to 8 volumes of blood. The products of the oxidation of the blood are expelled by the lungs and skin as carbonic acid and water. A portion also of the inspired oxygen combines with the nitrogen and other

Combination of oxygen with the blood.

Products cast off.

elements of the animal tissue; and, after this combination, the products are eliminated from the system in the excretions. It is the oxygen of the atmosphere alone that has the power of oxidizing and removing the waste of animal life. The nitrogen is merely present as a diluent, which modifies the stimulating effect of the oxygen. Air once used loses its vitality, and becomes unfit to sustain life. Air, too, that is loaded with decomposing matter will not sustain life in health, because the oxygen of the air is absorbed or used up by the organic matters which are present when undergoing decomposition. Air, carrying decomposing matter and the germs of disease, is also directly injurious, because it becomes the vehicle which conveys into the human system the organic elements undergoing decomposition, or a specific poison which has the power to reproduce itself in organic structures; consequently, the effect of breathing vitiated air, or air loaded with decomposing or other deleterious matter, is to lower the natural vitality so as to render the human subject susceptible of disease, and then the corruption of the blood may take place from contracting the poisonous elements just as effectually as if it were inoculated with any known poison.

Causes of vitiation of air.

Action of decomposing matter in organic structures.

Effects of breathing bad air.

Water is the agent used for conveying nutrition to every part of the animal system; and, after fulfilling this mission, it becomes the vehicle for conveying away all those soluble compounds which have subserved their purpose in the animal economy. Hence it is found that nearly all the soluble substances cast off by the animal creation are present in the urine. The necessity of pure water is as great as that of pure air. Deleterious matters present in water, as a rule, act more speedily than those present in the air, because, when conveyed in water, they pass at once by the rapid process of venous absorption into the system.

Use of water by animals.

All soluble substances in urine.

Speedy action of bad water.

The food we daily eat goes to make up for the daily loss and waste, or to replace those substances which

Food and its purposes.

have been expired, or passed away in the excretions. The process of nutrition is carried on by the blood. By means of digestion and assimilation food is converted into blood, and only those substances capable of producing blood are of real value as food; the rest are discarded and passed away in the solid excrements: consequently, in the fæces is found all undigested food, as well as the solid matters which are excreted by the animal system. The nitrogenous compounds, all of which are soluble in water, are principally passed away in the urine. The nitrogen present in the fæces is very small, and is principally derived from the liquid which is secreted in order to assist the passage of the solid fæces through the system.

All food should be capable of making blood.

Nitrogen in urine.

Small quantity nitrogen in fæces.

If the various processes carried on in the vegetable kingdom are now considered, we shall find, when studying the physiology of vegetable life, that oxygen, which is of such vital importance to the animal creation, is, simply as oxygen, of no special service to the vegetable kingdom; but it has been arranged, in the good order of Providence, that all the agents, whether air, water, or food, that have subserved the use of animals, and have ceased to promote animal life (having certainly become converted into agents destructive to its existence) have, by this very process, been made fit agents for the support of vegetable life. The vegetable kingdom utilizes those waste elements which have been cast off by the animal kingdom, and, after utilizing them, retains only those substances which the air or water had originally taken up from the animal, and in its turn, again gives up the air, water, and food, in a fit and healthful state for the use of animals.

Study vegetable physiology.

Oxygen not required by vegetables.

Air, water, food used by animals, purified by vegetables.

The foregoing simple physiological facts should be well understood, for in rightly comprehending them lies the whole secret of successfully carrying on sanitary operations, and dealing in a scientific and proper manner with those compounds which are constantly being eliminated from the animal system, and which

Necessity for understanding animal physiology.

are destined to become the food of the vegetable kingdom.

In nature it has been provided that all those matters that have once served the purpose of the animal economy, if not at once brought into contact with the vegetable kingdom, shall undergo change, so as to render them fit to be again used by the animal creation. Thus, urine and fæces are capable of undergoing change. By decomposition portions escape as gases into the atmosphere, which being dispersed by the wind soon become food for plants. Others, again, combine with the mineral constituents of the earth. The process is not so rapid as when all these matters are taken at once to the field, but the cycle is nevertheless as complete, for, sooner or later, they all go to administer to the wants of the vegetable kingdom, and poor ignorant man alone suffers for the delay, for, in the incipient stages of self-purification, the matters evolved have proved highly injurious to health and life, either by causing or aggravating the type of a certain class of diseases. The cause of disease is external to the human body; it is not the natural effect of existence, but it is the penalty of neglect, abuse, and also of want. Every disease has its own type, its own specific germ of generation. Every germ of disease requires conditions suitable for its development. When the human body first contracts disease, every effort is made to throw it off by those channels provided for the secretions and waste products; and when diseases of a certain type become epidemic, the cause may be looked for in the rapid development of the germs of disease under favourable conditions. It is difficult to conceive how small an amount of matter the germ may be in zymotic diseases, and how rapidly it may develop. We know with what rapidity a single microscopic cell of yeast will develop countless multitudes of cells, with the power of bringing favourable matter into a rapid state of fermentation. So it may be that a single infected person will, under

Effects of decomposition.

What disease is the result of.

Germs of disease.

Rapidity with which germs develop.

favourable conditions, become the prolific centre of infection. So easily are the seeds of disease spread, that it becomes only a matter of common prudence to strive to maintain the body in health, by removing those causes which tend to lower vital energy, and to dispose of, in an expeditious and safe way, all those matters given off by the human body, whether in health or disease, for we know that "every imprudence carries its own punishment." If the air of heaven is vitiated, the water rendered impure, or our food improper or insufficient, the body is robbed of life-giving elements, and soon succumbs to disease and death. It is the true aim and object of the Sanitary Engineer to assist Nature in her great but simple operations, to facilitate the purification of the air, to remove dangerous impurities from water, to supply abundance of these life-giving elements, to remove, as speedily as possible, before decomposition commences, all those matters eliminated from the animal system, together with all other decomposing refuse.

Effects of impure air and water.

Object of Sanitary Engineer.

Wherever masses of human beings congregate, whether in towns or villages, or in armies in the field, camp, or barrack, an artificial existence, to a certain extent, springs up. Each individual is no longer dependent upon himself; the habits of those around him influence his own position. The preservation of the health of every class in a community is equally important to the rich and poor. It is important to the wealthy that the poor should be kept in health, for the influence of infection, once introduced into the dwellings of the poor, often spreads far and wide, and is no respecter of persons. It is important to the poor man, as his health is his wealth.

Artificial existence in towns.

Preservation of health, importance of to all classes.

Sanitary laws and regulations are intended to give power to communities which single individuals cannot possess, *viz.* the power to promote general measures calculated to secure or improve the state of public health. In this country it so happens that the sanitary laws, to

Intention of sanitary laws.

Sanitary laws permissive.

a certain extent, are permissive, so that we see some districts in which the law is rigidly enforced, while, on the other hand, community after community is still found living in the most unsanitary condition, and disease and death reign supreme. No effort is made to remedy the state of neglect which may still be found in many undrained or ill-drained places. The Local Authorities are not always imbued with the true spirit of humanity; money considerations are with them often of greater importance than the question of life and health, and it not unfrequently happens that political capital is made out of sanitary agitation. The advocates of filth and dirt appeal to the breeches-pocket—too often with success—thus literally fulfilling those lines written by the poet Burns—

> "Man's inhumanity to man
> Makes countless thousands mourn."

The authorities in many towns appear to overlook the hard fact, that while they remain inactive, disease and death do not.

Power of Local Government Board to compel prosecution of sanitary works.

The Local Government Board has now the power to compel communities that have neglected their sanitary duties, to introduce proper measures, or the works may be performed for them; but, alas! at present, in how few places requiring attention has this power been exercised.

Historical notice.

If we refer to the page of history, we shall find that, in all ages of the world, wherever civilization advanced to any degree of refinement, there sanitary measures were invariably adopted. Thus, works of water-supply, sewerage, and temples of health, were constructed in all the ancient cities of the world. Many of these works have outlived the destruction which has doomed more imposing but less useful structures. Alexandria, Carthage, Herculaneum, Jerusalem, Nineveh, Rome, and many other cities, had a complete system of sewers and waterworks. In Rome, after the lapse of twenty-

Works carried out in ancient cities.

five centuries, the Cloaca, constructed when she was in the meridian of her power, is still retained, and performs a similar duty for modern Rome as that intended to serve the ancient city. Many works executed at this period of the world's history were of so stupendous a character as to rival the largest works of the present day, and they bear the strongest evidence of the clear knowledge of the sanitary appliances required for every large and populous city. Under the Mosaic dispensation sanitary laws were religiously observed; hence the discoveries made in ancient Jerusalem in modern time are full of interest. In the works here executed we see that the Jews possessed a clear knowledge of the necessity of removing all decomposing matter, as expeditiously as possible, to a place outside their city, and that when so removed, they knew how to dispose of it.

Cloaca of Rome

Mosaic dispensation.

From Dr. Whitty's excellent work, 'On the Water Supply and Sewerage of Jerusalem,' we learn that "Eusebius, who was a native of Palestine, and died there about the year 340," thus quotes Timocrates, the Surveyor of Syria, who stated of Jerusalem, "The whole city flowed with water, so that even the gardens were irrigated by those overflowing waters out of the city."

Sanitary works of Jerusalem.

Timocrates.

Dr. Whitty, further quoting from a paper by the Rev. George Williams, B.D., Senior Fellow of King's College, Cambridge, upon recent discoveries of Dr. Pierotti, says, "The situation of the Temple appears to be fixed, beyond all possibility of doubt, by the recent discovery, by Signor Pierotti, of the complete water system connected with the Hebrew Temple, still existing as entire as when it was in daily use during the period of the Jewish Commonwealth. The perfect preservation of this complicated system of aqueducts, drains, and reservoirs, is owing to the fact that they are excavated in the solid rock, and therefore have not been affected by the demolition of the structures above,

Dr. Whitty on the sanitary works of Jerusalem.

except in so far as they may have become partially blocked up by the accidental falling in of the *débris* of the ruined buildings."

Sewerage of the Temple of Jerusalem.

"Had history been silent on the subject, yet we should have been forced to conclude that there was a very complete system of sewerage connected with the Temple, introducing a large quantity of water to dilute the blood, which would otherwise have a tendency to coagulate, and carrying off the blood and offal from the sacred precincts." This history tells us was actually the case, and the supply of water was so managed as to flush the whole court, and carry off the blood of the numerous sacrifices. The drains leading from the Temple, and probably from the city, discharged themselves into a pit, which is now called the "Fountain of the Virgin," and which communicates by means of a channel in the rock, with another pit now traditionally called the "Pool of Siloam," but which there is every evidence to show is not the true "Pool of Siloam."

Use of tanks.

"It is a necessary consequence of the Fountain of the Virgin having been originally a cesspool, if that be admitted a fact incapable of being controverted, that the Pool of Siloam (now so called) was likewise a cesspool, formed for the purpose of receiving the liquor from the upper cesspool, in order that the manure in it might become sufficiently desiccated to be in a fit state for removal by the gardeners who purchased it, and that the tunnelled conduit was that through which the moisture was drained off into the lower cesspool, or liquid-manure tank." We find from the Mishna:—

Mishna.

"There was a certain cave beneath the altar whereby filth and uncleanness were carried down into the Valley of Kedron, and the gardeners paid so much money as would purchase a trespass offering for the privilege of fertilizing their gardens with it." The liquid matter, after leaving the traditionary Pool of Siloam, was then used, as it is at the present day, for the purpose of irri-

gating the king's gardens. From this description of the outfall works of the sewerage of ancient Jerusalem we learn that the sewage was collected in tanks, the solid matter was removed from it and sold, and the liquid was afterwards used for the purpose of irrigation, just as is the most approved practice of the present day. Although these ancient examples of sanitary works were executed when art and science had reached a high degree of excellence, we come to a period in history when both art and science declined, and with them the prosecution of those sanitary works which were of so beneficial and useful a character; in fact, the benefits derivable from sanitary science seem to have been forgotten and ignored, and the people sunk to the lowest depths of sanitary neglect, from which the powerful voices of plague, typhus, and cholera were the first to arouse them. Little more than a quarter of a century has elapsed since efforts were made in this country to improve the sanitary condition of the great masses of the people. But short as the period has been, much good has been done, many lives have been saved, and much sickness and misery averted. The modern works of sewerage and water-supply have been experiments made for improving the state of public health, and that they have accomplished the end for which they were inaugurated will be seen from Table No. 1, which contains the results in twelve towns that have been selected from the records collected by the medical officers of the Privy Council, and published in the ninth Report of the department.

Period in history when sanitary science declined.

Voice of disease awakened people.

Good results of sanitary works.

Works of sewerage and water-supply experiments to improve public health.

Records of Medical Officers Privy Council.

In examining the Table it will be seen that in some cases the actual saving in health has not been great. For example, at Rugby. This may be accounted for from the fact that it is far more difficult to reduce the death-rate in a healthy district and make it more healthy, than it is to reduce an unhealthy district and make it comparatively healthy. It will be seen that, in the case of Rugby, before the prosecution of the works the rate

Effect of sanitary works in comparatively healthy districts.

Rugby mortality.

of mortality was comparatively low. Since the completion of these works even that low rate of mortality has improved, while those particular diseases which are attributable to sanitary neglect have considerably declined.

Table No. 1.

TABLE No. 1.—Showing the RESULTS of SANITARY WORKS.

| Name of Place. | Population in 1861. | Average Mortality per 1000 before Construction of Works. | Average Mortality per 1000 since Completion of Works. | Saving of Life per cent. | Reduction of Typhoid Fever rate per cent. | Reduction in rate of Phthisis per cent. |
|---|---|---|---|---|---|---|
| Banbury .. | 10,238 | 23·4 | 20·5 | 12½ | 48 | 41 |
| Cardiff .. .. | 32,954 | 33·2 | 22·6 | 32 | 40 | 17 |
| Croydon .. | 30,229 | 23·7 | 18·6 | 22 | 63 | 17 |
| Dover .. .. | 23,108 | 22·6 | 20·9 | 7 | 36 | 20 |
| Ely .. .. | 7,847 | 23·9 | 20·5 | 14 | 56 | 47 |
| Leicester .. | 68,056 | 26·4 | 25·2 | 4½ | 48 | 32 |
| Macclesfield | 27,475 | 29·8 | 23·7 | 20 | 48 | 31 |
| Merthyr .. | 52,778 | 33·2 | 26·2 | 18 | 60 | 11 |
| Newport .. | 24,756 | 31·8 | 21·6 | 32 | 36 | 32 |
| Rugby .. .. | 7,818 | 19·1 | 18·6 | 2½ | 10 | 43 |
| Salisbury .. | 9,030 | 27·5 | 21·9 | 20 | 75 | 49 |
| Warwick .. | 10,570 | 22·7 | 21·0 | 7½ | 52 | 19 |

Effect of sanitary works in staying the ravages of disease.

It will be seen by a glance at the above Table that the sanitary works which have been carried out in the places named have had a marked effect in staying the ravages of disease and death, and they have also had the effect of prolonging the average duration of life.

Good that has arisen from sanitary operations.

The good that has arisen from the prosecution of sanitary works, wherever properly carried out, may be taken as the harbinger of more hopeful times, when the benefits of sanitary measures will be better understood, and more extensively adopted. How much society annually loses by preventible disease, it is impossible to fully estimate, as health is so intimately connected with all the branches of every-day life. We know that the

Physical ability basis of value.

power of physical ability forms the basis of the value of all descriptions of labour, and that the full value of work cannot be got from a sickly and consequently feeble population; therefore, those communities that are in a bad sanitary state are considerable losers. The national

National prosperity of country impeded.

prosperity of the country is impeded by the undue amount of sickness we have to support, and the losses of human life we have to sustain. If upon no other than economical grounds, it is true economy to spend some little of our earnings in the prosecution of sanitary works. Health is the capital of the labouring man. It is better to give health than alms, for an unsanitary state brings sickness, disease, and mortality, which are followed by pauperism, demoralization, and crime. Dr. Johnson says, "To preserve health is a moral and religious duty. For health is the basis of all social virtues. We can be useful no longer than we are well." In how many cases has preventible illness destroyed the prospects in life of its victims; how often has the invalid become a burden to his fellow-creatures; how often has a father of a family been stricken by typhus, and left his family chargeable to the rates. In how many cases has the loss of a paternal guide left families to grow up in a course of vice and crime, and become a permanent expense to their country. These are all matters that are really past calculation, but nevertheless we acknowledge the facts. "It too often happens that a man dies and his place is taken by another without cost to his employer, and less consideration is shown to him than would have been given to a horse or a dog, which could not be replaced without pecuniary outlay."

Health is capital.

Quotation fro Dr. Johnson.

Effect of illne and death.

Charges on rates.

Small consideration sho to man.

It has been found in unsanitary districts that sickness bears a regular proportion to the rate of mortality, and sanitary works can be measured by the £. *s.* *d.* saved. Dr. Lyon Playfair calculates that for every unnecessary death we have twenty-eight cases of sickness. Dr. Farr has computed the money value of the agricultural labourer at twenty-five years of age at 246*l.* 7*s.*, as being the estimate of his future wages, after deducting the necessary cost of maintenance. An estimate of the probable effect of the sanitary works can be propounded in this way: *First*, the saving in the cost of funerals,

Sickness bear a proportion mortality.

Dr. Lyon Playfair's calculations.

Dr. Farr's calculations.

Estimated va sanitary wor

inclusive of mourning and fees, which upon an average may be set down at 5*l.* each. *Secondly*, the saving by reason of the escape from sickness, with its cost, including the value of labour which is lost. To be upon the safe side, it may be taken, for every life saved by sanitary works, twenty-five persons would escape sickness, and that 1*l.* per case would represent but a moderate value of the result, including loss of time, physic, medical and other attendance. *Thirdly*, the value of the labour saved to the country by the prevention of premature death—for every adult female, 5*s.* per week, and for every adult male, 10*s.* per week, or a mean of 7*s.* 6*d.* per week, may be taken as the value of the labour, over and above the cost of maintenance. If a town which has carried out sanitary works compares its savings under the above heads, with its expenditure, it will be found, in the course of a few years, that, in all cases in which the sanitary works have been properly carried out, the money value of the lives saved, and the sickness averted, will exceed the full estimated cost of the works executed. The author, in his "Inaugural Address" as President of the Society of Engineers in 1868, made such a calculation, taking the town of Croydon as an example, which is here reproduced.

Number of cases of sickness prevented.

Value of labour.

Quotations from Inaugural Address, Society of Engineers.

Expenditure in Croydon.

EXPENDITURE IN CROYDON TO END 1867.

| | £ | s. | d. |
|---|---|---|---|
| Purchase of freehold lands .. .. .. .. | 50,000 | 0 | 0 |
| Construction of waterworks .. .. .. .. | 70,000 | 0 | 0 |
| Construction of sewers, sewage irrigation works, public baths, abattoirs, and general improvements .. .. .. .. .. .. .. .. | 75,000 | 0 | 0 |
| | £195,000 | 0 | 0 |

Mortality in Croydon.

The average mortality of the town of Croydon for seven years, previous to the construction of sanitary works, was 23·66 per thousand, and for thirteen years since they have been in operation it has been 18·64 per thousand, showing a saving of 5·02 per thousand per annum. The mortality in the year 1848 was 28·16 per thousand, and in the year 1867, 16·6 per thousand;

in 1848 the population was 19,380, in 1867 it was 50,750, showing that the population increased 160 per cent., and the death-rate reduced 40 per cent. between the extreme periods. The mean population for thirteen years since the works have been completed, and in successful operation, commencing with the year 1855, has been 37,375. By taking the mean saving of life of 5·02 per thousand, and multiplying it by the mean population in thousands, and again by the number of years, we get, 37,375 × 5·02 × 13 = 2439 lives saved. Of this number six-tenths, or 1463, would be adults, or persons above the age of twenty, but probably one-tenth of these would be infirm from age; by making this deduction we have still 1317 persons in the full vigour of life who have been saved. By using the figures before quoted, in connection with the lives saved, we shall get the money value of the benefits conferred by the works:—

Decline in mortality, increase in population.

| | £ | s. | d. |
|---|---|---|---|
| 2439 funerals, &c., saved, at 5*l.* each .. .. | 12,195 | 0 | 0 |
| 2439 × 25 = 60,975 cases of sickness prevented, at 1*l.* .. .. .. .. .. .. .. .. .. | 60,975 | 0 | 0 |
| 1317 value of labour at 19*l.* 10*s.* for 6½ years.. | 166,929 | 15 | 0 |
| | £240,099 | 15 | 0 |

Money savings in Croydon.

In this case, while 195,000*l.* had been expended in all the public works, they had effected a saving equal to 240,000*l.*, so that in the short space of thirteen years a sum exceeding by 25 per cent. the total expenditure for works executed and the purchase of freehold property, has resulted from the prosecution of sanitary measures. Although it has here been attempted to put a money value on life, we individually feel that life is priceless, and that we may look to the 2439 persons saved from the jaws of death in this single town, as the living testimony of the great value of sanitary works. To allow to perish by sanitary neglect is just the same as to take so many persons out of their homes, and forcibly put them to death; and yet if this were

Saving greater than expenditure.

Life priceless.

done the whole nation would revolt at the crime. Yet in how many instances do our local authorities calmly look on, while poor and innocent victims are condemned to breathe a poisoned atmosphere, or drink poisoned water, which is a great crime in the eyes of humanity.

Position taken by medical men.

The medical men of this country have, as a rule, acted like true philanthropists in generally taking the lead in all questions relating to the prevention of disease. To no body of scientific persons are the effects of an unsanitary condition made more painfully manifest.

Effects of disease in unsanitary localities.

Disease in unsanitary districts sits like a vampire on its victim, which is never satiated till the last drop of life-blood is exhausted. Medical men know full well that it is almost futile to apply their healing art in unsanitary places.

Effect of removal of patients.

The removal of the patient, even in the most rapid disorders of a zymotic type, to a healthy hospital, in a more salubrious neighbourhood, renders the effects of disease less fatal. The reason is obvious; if the patient remain in the region where he has contracted disease, and in which he is continually exposed to malarious influence, the case is in all respects like that of a man who is being murdered by slow and secret poisoning; the doctor may be called in, and he may prescribe for his symptoms, but the dose of subtle poison is still secretly administered, and as the cause of the diseased symptoms is not removed, the natural effects can rarely be prevented.

Influence of scientific press.

The scientific press of our country has done much to spread the knowledge of sanitary principles by exposing our faults and failings—by chronicling successful examples—by showing up in its true light the sanitary condition of various localities; in warning us of the danger that surrounds us; in advising us as to the steps we should take,—generally, in the elucidation of truth and eradication of error, and, finally, in the encouragement invariably given to the advancement and prosecution of sanitary science.

Alchymist of old in vain spent time in searching for th philosopher's stone.

The alchymist of old vainly expended his time in the search after the philosopher's stone, which was to convert all the baser metals into gold, or whereby he was to compound an elixir of life, that would restore to age the healthful elasticity of youth, and prolong human existence. In the prosecution of sanitary works we have discovered a real philosopher's stone, for such works have been abundantly shown to have added to the average duration of life, and in the utilization of those waste products which have hitherto been looked upon as dirt, rich and golden harvests have been, and still will be, produced.

Sanitary work a real philosopher's stone.

## VARIOUS PLANS PROPOSED IN CARRYING OUT SANITARY WORKS.

Success of sanitary works On what it depends.

The success of the prosecution of sanitary works is more dependent upon the character of the works executed than upon any salubrity or insalubrity of climate. This is seen from an examination of the rates of mortality in some continental towns. For example, we find that both Brussels and Paris, which have climates far more salubrious than that of London, have nevertheless a higher rate of mortality than London, proving conclusively, that the sanitary works of London are of a more effectual, and therefore more perfect character, and that they better fulfil their mission than those adopted either in Brussels or Paris.

Various modes for effecting the removal of decomposing matters.

Various modes have been proposed from time to time for effecting, or perfecting, the appliance within our towns for the removal of all decomposing matter, and various agents have been suggested for use in connection with the removal of those accumulations of filth and dirt which have been found to be so prejudicial to health and life. All the elements known to the

ancients have been laid under tribute for this purpose; fire, air, earth, and water have all been proposed and adopted, in their turn, as sanitary agents to be used in connection with the removal of such matter, and for securing the great objects sought by the sanitary engineer. The advocates of fire recommend that all the waste products of our towns and populous places should be committed to the flames.

Use of fire as sanitary agent.

Use of air as a sanitary agent.

A second set of advocates would have us believe that air is the best agent for removing those matters, and that the pneumatic is the proper system to be adopted.

Use of earth as a sanitary agent.

A third set of advocates recommend mother-earth as by far the best agent that can be used in connection with the removal of all fæcal and decomposing matter from the habitations of the people; while a fourth set of advocates maintain that the water-carriage system is the best, and the only feasible plan that can be adopted under the varied requirements of a town population.

Use of water as a sanitary agent.

None of agents proposed entirely effectual.

Upon careful consideration it must be seen that none of those agents which have been proposed fulfil all our requirements, when we have to deal with the question of removing, not only the fæcal matter, but other refuse from the houses and manufactories of our towns. For example, fire, air, and earth are of little use for removing and disposing of liquid filth; whereas water and air are incapable of being applied so as to deal with a very large mass of the accumulating matter of our towns, namely, the sweepings from streets, ashes, and solid garbage from houses, all of which are now required to be removed by manual and horse labour.

Purpose for which air and water proposed to be used.

Air and water have been proposed as the medium by which decomposing matter shall be conveyed through a properly-constructed system of pipes, or tubes, out of our towns, and then used for agricultural purposes.

Purpose for which fire proposed to be used.

Fire has been recommended simply as a means whereby decomposing matter may be destroyed, or rather converted, by rapid oxidization into harmless elements.

Earth and other materials of this character have from time to time been recommended and used, more with a view to deodorize and fix the elements of decomposition, so as to render the matter to be dealt with less baneful in its effects on health when accumulating in towns, and also as a means of preserving its manurial value.

Purpose for which earth is used.

Of all the systems that have been proposed, the water-carriage system is, in the opinion of the author, the best adapted to the varied requirements of a town population for effecting the speedy removal of the principal matter liable to decomposition. It will also be found equal to any other system in securing the manurial elements that have to be utilized; but it should not be overlooked that other systems are applicable, and may be adopted with manifold advantage when the circumstances are such as to debar the entire use of water-carriage.

Water-carriage preferred.

Systems applicable under certain conditions.

## WORKS OF SEWERAGE.

In carrying into effect the works necessary for the sewerage of a town, three distinct operations have to be performed:—

1st. The drainage of the surface.
2nd. The drainage of the subsoil.
3rd. The removal of fæcal and other liquid refuse.

Objects to be secured in works of sewerage.

The sewers of ancient cities were intended to combine two of these objects, or the removal of all surface-water and fæcal refuse. The early sewer works of this country were designed for conveying away surface drainage only, which, as a rule, was passed by short lines of sewers to the nearest natural outlet. It was illegal, prior to the year 1815, to pass fæcal matter into sewers. Such matter was generally allowed to accumulate in cesspools, either under the habitations of the people, or in close proximity thereto; but the growing evils of this

Work performed by ancient sewers.

Illegal to drain into sewers.

system were so great that, about the year mentioned, the laws which guarded sewers were by the tacit consent of the various authorities allowed to lapse. But it was not until the year 1847 that the first Act of Parliament was passed, which made it compulsory to pass fæcal and other matters of this character into sewers. Much difference of opinion has been expressed as to the mode in which the objects sought to be fulfilled by sewers ought to be carried out in practice. It may be taken as an ascertained fact that no abstract rule universally applicable can be laid down for the guidance of the engineer in the prosecution of works of sewerage, although there are some general principles which are common, and applicable to every town. Naturally there are conditions and circumstances which arise during the prosecution of sanitary works, and which differ in different places, which must guide the engineer as to the plan of sewerage he should adopt. In all sanitary works it should be laid down as a first requirement that the works shall be capable of fulfilling their sanitary mission. All questions relating to the pecuniary results that may arise from the profitable disposal of the matters to be dealt with, must be taken to be of secondary importance, although this question must not be entirely lost sight of.

Compulsory powers to drain into sewers.

Differences as to work to be performed by sewers.

No general principle can be laid down for guidance of engineer.

Sanitary works to be capable of fulfilling their mission.

Matters for consideration in designing works of sewerage.

The preliminary inquiry in a district will naturally embrace—

1st. The area of the district to be sewered.

2nd. The rainfall of the district, and the proportion it is intended to admit into the sewers.

3rd. The geological character and physical outline of the district.

4th. The present and prospective number of its inhabitants.

5th. The supply of water in the district.

6th. The sanitary appliances at present in operation, or to be adopted.

7th. The position of the outfall, and the mode of disposing of the sewage.

# AREA AND PLANS OF THE DISTRICT TO BE SEWERED.

Survey of district.

In order to arrive at correct conclusions as to what is necessary to be done in the way of sewerage within a district, a careful survey with levels should be made. Such survey should include not only the area of the district which may be under the jurisdiction of the local authority by whom the engineer may be engaged, but the area which is fixed by the natural configuration of the country around. It often happens that there are portions of other districts which naturally drain into the district to be dealt with; therefore it may be advisable to take into consideration the volume of sewage or rainfall which may be contributed from such areas. Where several districts governed by different local authorities lie in close proximity, and within the same natural drainage area, it will be well for the engineer to take cognizance of the fact, and to make such recommendation, when it is advisable, as may lead the several authorities to combine either for the purpose of sewerage or for the purpose of disposing of the sewage of their respective districts. In many cases where a large amount of rain falls upon the higher lands above the district to be dealt with, the natural outlet for which is through the district, it will be well to conduct such rainfall by its natural channels, or, in some cases, it may be requisite to construct special artificial channels for its passage, so as not to unduly burden the sewers with a large and intermittent volume of water. It is indispensable that the drainage area above the district to be dealt with should be taken into account in every case when artificial channels are required to be provided for the conveyance of upland waters through the district to be dealt with.

Survey in some cases to embrace adjoining district.

Mode of dealing with rainfall of high districts.

Drainage district to be defined.

It not unfrequently occurs that the engineer is called upon to define a district for the purposes of adopting the Local Government or other Drainage Acts; and in doing this he should take into consideration the natural drainage area, and to make the district selected "compact and practicable." As to surveys, in districts in which it is proposed to carry out works of sewerage, the engineer will find that the Ordnance Department have published accurate geometrical plans and surveys of many places which will often be found of great service to him when designing works of sewerage. In districts in which no accurate plans exist, special surveys will have to be undertaken, and it is desirable, when such surveys are made, that they should be conducted on trigonometrical principles, in order they may be as accurate as possible. In the suggestions which were issued by Mr. Robert Rawlinson, C.B., from the Local Government Act Office, the following instructions are given as to the preparation of plans and sections of any proposed works of sewerage:—"A general plan, exhibiting the area which will be affected by the proposed works, should be laid down to a scale of not less than two feet to a mile. It should have figured upon it the levels of the centres of all streets and roads at their intersections and angles, and at every change of inclination. Where a district is near the sea it should show the high and low tide level of the sea, and where there is a river the summer and flood water levels should be recorded. Permanent bench marks, having reference to the surface levels, should be cut on public buildings, &c., throughout the district, and also be marked on the plan. Sections should accompany this plan, upon which the levels of the cellars should be shown. Such a plan might be used for showing lines of main sewers and drains, lines of water-pipes and gas-mains. The lines of main sewers and drains should have the cross-sectional dimensions and gradients distinctly marked upon them. The dimensions of water and gas

Surveys.

Ordnance maps.

General plan.

What should be shown on plan.

pipes should also be shown in figures or by writing."

Detail plan.

"A detailed plan for the purposes of house drainage, paving, the sale and purchase of property, &c., should be constructed to a scale of not less than ten feet to a mile. Upon this plan should be exhibited all houses and other buildings, bench marks, the levels of streets and roads, of cellars, of the sea at high and low tide level, and the summer and flood level of rivers. Three feet by two feet will be a convenient size for the sheets of this plan, and by representing the marginal lines of the sheets upon the general plan, the general plan will become a very useful index."

Index to general plan.

In districts in which it is deemed desirable to carry out works of sewerage as speedily as possible, the Local Government Department do not place any unnecessary obstacle in the way of carrying out such works; and in any case where no plans exist they will, as a preliminary step, be satisfied, on certain conditions, with less carefully prepared plans, as before suggested, for they state:—"As, however, it may occasionally be desired to carry out works piecemeal, with a view to save the time which would be occupied in the preparation of a complete plan from actual survey, it will be sufficient, in the first instance, to furnish a general plan of streets and roads only, with the surface levels, and those of the deepest cellars, and the proposed scheme of works shown thereon, after which the works can proceed in sections; but with each separate application for sanction to a loan a correct plan and section or sections should be submitted, accompanied by detailed estimates and specifications. It should be understood, however, that the complete plan of the entire district must be proceeded with, so that when the works are finished the Local Board and this office may possess a proper record."

Plans that may be used under urgent circumstances.

When carrying out sewerage or sewage utilization works, when it is necessary to put in force the compulsory powers, authority is conferred either by provisional order issued by the Local Government Board, which

Compulsory powers to carry out works.

requires to be confirmed by Parliament, or by the direct sanction of Parliament. In either case it is now necessary to deposit plans, and the Standing Orders of Parliament require that such plans should be drawn to a scale of not less than four inches to the mile. They are to show the line or situation of the whole work, or any lateral deviation which may be proposed, and if, upon the line of the proposed work, or within the limits of deviation, unless the plan shall be drawn to a scale of not less than a quarter of an inch to every 100 feet, then an enlarged plan of any "building, yard, court-yard, or land within the curtilage of any building, or of any ground cultivated as a garden," is to be added, and it is to be drawn to a scale of not less than a quarter of an inch to every 100 feet. Sections of the work require to be prepared, which shall be of the same horizontal scale as the plan, and have a vertical scale of not less than one inch to every 100 feet; and should it be intended to make any alteration "in the water level of any canal, or in the level or rate of inclination of any turnpike road, public carriage road, or railway," cross-sections must be provided having a horizontal scale of not less than one inch to every 330 feet, and a vertical scale of not less than one inch to every 40 feet. In addition to the plans required for Parliamentary purposes, or for deposit at the Local Government Act Office, the engineer should in every case prepare detail drawings of the works he is about to execute, for the guidance of those who may have to carry them out. Such details should be drawn to as large a scale as compatible.

Parliamentary plans.

Scale of plans.

Necessity of detail drawings.

# RAINFALL AND SEWERS.

The amount of rain that falls in a district is computed from the amount collected in the rain-gauge. There are few towns or districts at the present day in which some person or other does not keep a rain-gauge, and register the rainfall. Numerous observations of the amount of rain falling in various districts are annually compiled and published by Mr. Symons, and such tables are of great importance and inestimable value to the engineer in designing works of sewerage. Having ascertained the amount of rain falling in the district to be dealt with, which, for the purpose of being practically useful, should show the maximum quantity of rain that falls in the shortest time, as all sewerage works must be calculated to convey away, either by the sewers or by storm-water overflows, or special works constructed for the purpose, the maximum amount of rain without flooding or inconvenience to the inhabitants of the district.

Use of rain-gauge.

Mr. Symons' Rainfall Tables.

Maximum amount of rain should be ascertained.

Much difference of opinion has been expressed with regard to the advisability or not of admitting rainfall into sewers. Some persons propose that in every district the rainfall should be entirely separated from the sewers; but unfortunately the persons who make this proposition have had, as a rule, a very limited experience as to the effects of rainfall on sewers and sewage. In proposing the separation of the rainfall from the sewers, the fulfilment of two objects is sought: 1st, to increase the manurial value of the sewage; and, 2nd, to give to the streams of the country the natural volume of water due to the rainfall within their collecting area; or, in the words of Mr. J. O. Ward, "to convey the rainfall to the rivers and the sewage to the land." In some districts it may be important to keep the rainfall as far as

Difference of opinion as to admitting rainfall into sewers.

Objects sought to be attained by exclusion of rainfall.

possible out of the sewers; but there are other districts in which no material advantage would arise from excluding rainfall from sewers; but, on the other hand, positive injury may accrue to the fresh-water streams, by reason of the polluted matters brought down in time of storm. For example, in urban districts, which are closely inhabited, or in which there is a great traffic, experience clearly shows that the rainfall in such districts becomes as impure as the most impure sewage found in sewers. The analysis made by Professor Way of surface drainage water, flowing from the principal streets of London, shows beyond doubt that the water contributed to sewers, in time of rainfall, is quite as impure as that of any sewage. The Tables Nos. 2 and 3 on the opposite page give the analysis of street water, and the analysis of the matters found in such water.

Rainfall in urban districts.

Professor Way, analysis of street water.

From Tables No. 2 and No. 3 it will be seen that in districts in which there is great traffic, or which are closely built upon, if a system of sewers is to be carried out which shall intercept all impurities from the fresh-water courses of the country, it will be absolutely necessary to admit a large proportion of the rainfall into the sewers, in order that it may be dealt with so that it may be purified and rendered fit to be passed into the natural streams of the country. In districts where the rainfall is of small amount, it is generally loaded with impurities; while with a heavy rainfall the water last contributed may flow off comparatively pure. Taking this fact into consideration, it is easy, in many districts, to design a system of sewerage combining the admission of small amounts of rainfall into the intercepting sewers of a town, while in time of heavy rainfall the comparatively pure water should not pass into the intercepting sewers, but should flow on to its natural outlet. The arrangement by which this may be accomplished is the reverse of the principle already put in practice by Mr. Bateman, C.E., in the Manchester Waterworks, for separating pure and impure water, and is so very simple,

Effect of traffic, &c., on rainfall.

Small rainfalls give impure water; large rainfalls pure water.

Scheme for intercepting impure rainfalls from rivers.

TABLE No. 2.—Showing the ANALYSIS of STREET WATER.
By PROFESSOR WAY.
The water was intercepted in its passage to the sewers.

| Number of Bottle. | Name of Street. | Quality of Paving. | Quality of Traffic. | Residue in an Imperial Gallon. | | |
|---|---|---|---|---|---|---|
| | | | | Soluble. | Insoluble. | Both. |
| | | | | grains. | grains. | grains. |
| 1 | Duke Street, Manchester Square .. .. .. .. | Macadamized | Middling | 92·80 | 105·95 | 198·75 |
| 7 | Foley Street (upper part) | „ | Little .. | 95·30 | 116·30 | 211·43 |
| 5 | Gower Street .. .. .. | Granite .. | Middling | 126·00 | 168·30 | 294·30 |
| 12 | Norton Street .. .. .. | „ .. | Little .. | 123·87 | 3·00 | 126·87 |
| 3 | Hampstead Road (above the canal) .. .. .. | Ballasted .. | Great .. | 96·00 | 84·00 | 180·00 |
| 4 | Ferdinand Street .. .. | „ .. | Middling | 44·00 | 48·30 | 92·30 |
| 2 | Ferdinand Place .. .. | „ .. | Little .. | 50·80 | 34·30 | 85·10 |
| 10 | Oxford Street .. .. .. | Granite .. | Great .. | 276·23 | 537·10 | 813·33 |
| 6 | „ „ .. .. .. | Macadamized | „ .. | 194·62 | 390·30 | 584·92 |
| 11 | „ „ .. .. .. | Wood .. .. | „ .. | 34·00 | 5·00 | 39·00 |

TABLE No. 3.—Showing the ANALYSIS of the SOLUBLE MATTER in DIFFERENT SPECIMENS of STREET DRAINAGE WATER.

By PROFESSOR WAY.

| | Grains in an Imperial Gallon. | | | |
|---|---|---|---|---|
| | Great Traffic. | | Little Traffic. | |
| | Granite, No. 10. | Macadam, No. 6. | Granite, No. 12. | Macadam, No. 7. |
| Water of combination and some soluble organic matter .. .. | 77·56 | 29·07 | 22·72 | 13·73 |
| Silica .. .. .. .. .. .. .. | 0·51 | 2·81 | .. | .. |
| Carbonic acid .. .. .. .. .. | 15·84 | 12·23 | None. | None. |
| Sulphuric acid .. .. .. .. .. | 36·49 | 38·23 | 46·48 | 34·08 |
| Lime .. .. .. .. .. .. .. | 6·65 | 13·38 | 25·90 | 16·10 |
| Magnesia .. .. .. .. .. .. | None. | 23·51 | Trace. | 3·50 |
| Oxide of iron and alumina, with a little phosphate of lime .. .. | 2·58 | 1·25 | .. | .. |
| Chloride of potassium .. .. .. | None. | 10·99 | None. | 2·79 |
| „ sodium .. .. .. .. | 53·84 | 44·88 | 18·44 | 19·70 |
| Potash .. .. .. .. .. .. | 82·76 | 18·27 | 8·75 | 5·23 |
| Soda .. .. .. .. .. .. .. | .. | .. | 1·58 | .. |
| | 276·23 | 194·62 | 123·87 | 95·13 |

and not liable to derangement, that it may easily be introduced in practice, when it will commend itself. It is constructed in accordance with the well-known laws, that the combined effect of horizontal projection and of gravity on a stream of water issuing from an orifice, cause the liquid to assume the form of a parabolic curve; therefore, when it is desired to project a stream a certain distance horizontally, it follows, as a natural sequence, that when the velocity of projection is small (owing to the longer interval of exposure to effect of gravity), comparatively the space fallen through in reaching the desired point will be great; while, when velocity is great, the space fallen through will be small. Plate XV., Fig. 9, shows the arrangement. In this case the sewer for conveying rainfall is assumed to be 2 feet diameter, and has a rate of inclination of 1 in 550, and it is supposed to cross over the intercepting sewer on its course to a river. At the point the sewers cross an opening is made in both sewers, or in the bed of the rainfall sewer, and in the crown of the intercepting sewer. In this case the opening is supposed to be one foot wide, and at the point of opening a sudden fall is given to the rainfall sewer, making a step of 2 feet in the sewer. When 3 inches in depth of rainfall flows through the rainfall sewer, the velocity of the current will be 1·6 foot per second, and in order to pass the opening 1 foot wide, the step forming a weir should be 6·29 feet; but as it is only 2 feet, all the water flowing down the sewer would pass into the intercepting sewer. When 6 inches in depth of water is running through the 2-feet rainfall sewer, the velocity of current will be 2·25 feet per second, and in order to pass the opening the step should be 3·25 feet, so that this quantity will also pass into the intercepting sewer. When the rainfall sewer runs half full, the velocity will be 3 feet per second, and in order to pass the opening the step or fall should be 1·70 foot; but as in this case it is stated to be 2 feet, all the water brought down by the rainfall sewer will

Gravity.

Arrangement for intercepting rainfall.

pass over the opening, and would be discharged direct into the river, instead of passing into the intercepting sewer; and so by adjusting the width of the opening into the intercepting sewer, or the amount of fall at the weir, any given amount of rainfall may be made to pass into the sewers, or be discharged into the streams of the district, as may be required; thus when the rainfall is very impure it will pass into the intercepting sewers; but when the rainfall is great and pure, the velocity is such that it will leap over the opening provided for the interception of the impure rainfall, and pass on to its natural outlet.

Rainfall in rural districts.

There are some districts of a rural character in which the surface drainage is generally comparatively pure, and consequently it could therefore be conveyed to the ordinary water-courses of the district without detriment. On the question of the admittance of rainfall into sewers, Professor Way, speaking of the analysis of the surface water of London, states that, "so far as London is concerned, and considering only the composition of the liquid which reaches the sewers in the time of rain from the streets, it seems pretty certain that it would be as valuable in a manurial point of view as the ordinary contents of the sewers. There would seem no reason, therefore, to exclude such waters on the ground of the dilution and deterioration of the sewage, to which they might be supposed to lead."

Rain acts as a scavenger.

In considering the question of the amount of rainfall to be admitted into sewers, it should always be borne in mind that rain acts as a scavenger in washing the air and the surface of the streets, courts, yards, roofs, &c., and conveys away an immense amount of impurity. In some foreign countries in which there are distinct periods of wet and drought, it may always be desirable to convey away the excessive storm-water by a distinct set of sewers, while the sewage proper may be conveyed away by another set of sewers, the reason for which is obvious, as, owing to the large amount of rainfall compared with

Experience in foreign countries.

the comparatively limited quantity of sewage, the channels for conveying away the combined rainfall and sewage would have to be constructed so much out of proportion to the ordinary work the sewers would have to perform in periods of drought, that a sufficient velocity of current would not be maintained in the sewers to keep them clear, and consequently they would become sewers of deposit, and might prove highly injurious to health, as the deposit would naturally accumulate at those periods of the year when decomposition was most active.

Desirable to intercept rainfall when pumping has to be resorted to.

In some districts, owing to the natural position of their outfall, artificial power may be required to lift the sewage to a considerable height, in order to dispose of it. In this case it would be prudent for the engineer to consider how much rainfall he can exclude without polluting the natural streams of the district. In studying the question of rainfall it would be well always to bear in mind that experience has shown that

Dilution does not always injure sewage.

dilution of the sewage by rainfall does not materially diminish its total collective value, although it may add considerably to the expense of its application for agricultural purposes; and, consequently, in order to secure the best possible return, it may be desirable to exclude as much rainfall from the sewers as possible in every scheme in which pumping has to be resorted to, in order to reduce the expenses of sewage disposal to a minimum.*

Seaside towns.

In many seaside places, or in districts in which the low-lying sewers are tide-locked, it will be well to convey away the rainfall, by sewers distinct from those which collect the ordinary sewage. To what extent this may be necessary, the engineer will consider after fully taking into account the principle of interception, which is hereafter referred to.

Provision to be made for percentage only of rainfall.

In all cases in which rainfall is admitted into sewers

* When sewage is intended to be treated chemically rainfall should be excluded as far as possible from the sewers.

it is found by experience that only a certain percentage of the actual rain finds its way to the sewers, the other portion being either evaporated or absorbed, and it generally occurs that when we have the largest rainfalls, as in thunder-storms, evaporation and absorption are usually most active. In experiments made some years since by Mr. Dickenson, on the rainfall in the district of the Colne, he found, on an average of seven years, that from April to September, inclusive, 93 per cent. of rainfall was evaporated, and 7 per cent. absorbed, equal to 1192 tons of water per acre evaporated; while but 91 tons per acre were absorbed or filtered into the ground; and from October to March, inclusive, 25½ per cent. of water was evaporated, equal to 360 tons of water per acre, and 1052 tons per acre were absorbed.

Mr. Dickenson

The intercepting sewers of London have been constructed to convey rainfall at the rate of ¼ inch in depth over the whole area drained every twenty-four hours, at the time the maximum flow of sewage is being discharged. Provision is made to deal with a larger amount of rainfall than this by means of storm-water overflows, communicating with outfalls into the Thames which have been retained or specially provided in the natural drainage valleys of the district. From the discussion which took place at the Institution of Civil Engineers, after papers had been read on the drainage of London and Paris, it appears that in 1857 Messrs. Bidder and Hawksley found, in the case of London, that with a rainfall of 2·90″ in twenty-six hours, Savoy Street sewer delivered 64·5 per cent., Ratcliffe Highway sewer 52 per cent., while Mr. Haywood found in the same storm that London Bridge sewer discharged 53 per cent. Mr. Haywood, in April, 1858, had gaugings taken of the same sewer, "when ·24 of an inch of rain fell in an hour and a half, he then found that 74 per cent. of the total quantity ran off, leaving 26 per cent. to be absorbed or evaporated. Of a rain-storm of ·54 of an inch, in five hours,

Amount of ra admitted into the sewers of London.

Messrs. Bidde and Hawksley

Mr. Haywood

in June, 1858, there was delivered into the Irongate sewer, which drained an area entirely paved and built over, as much as 94·5 per cent. of the total rainfall; and of all the storm-gaugings he had made, that was the greatest percentage he ever knew discharged by a sewer. In August, 1858, with a rainfall of ·48 inch in one hour and two-thirds of an hour he found only 78 per cent. of the total quantity discharged into the Irongate sewer." The author has found that the amount of water contributed in various districts depends very much upon the character of the surface which receives the rainfall. In districts in which the geological character is porous, the rain contributed to the sewers is very small. For example, in the case of Croydon, where the geological formation principally consists of gravel overlying chalk, the amount of rain contributed by a storm of ·72 of an inch, in twelve hours, in October, 1865, did not yield more than one-tenth of it to the sewers. In a district in Warwickshire, on the new red marl formation, the surface of which is almost entirely impervious, provision was made by the author to lead off a rainfall of 1 inch in twenty-four hours, together with one-half the maximum quantity of sewage in six hours, taken at 5 cube feet per head in twenty-four hours, and the sewers were found to be by no means too large. In the strongly fortified town of Dantzic, the geological formation of which is principally sand, and the district very flat, the author made provision for carrying off a quarter of an inch of rainfall in twenty-four hours, together with 2 cube feet per head of sewage in eight hours.* The volume of water supply in this district is about 3 cube feet per head in twenty-four hours, and the sewage was calculated at 4 cube feet in twenty-four hours. The rainfall in this district is about 20 inches annually, but is distributed on an

Amount of water depends on character of district.

Experience in gravel and chalk at Croydon.

Experience red marl of Warwickshire.

Calculations for town of Dantzic.

Volume of water supply Dantzic.

Distribution of rainfall of Dantzic.

* It is the practice of some engineers to calculate the volume of sewage to be dealt with as equal to one-half flowing off in six hours, or two-thirds in eight hours.

average of years over 270 days per annum, and there are only fourteen days per annum when the rainfall equals or exceeds a quarter of an inch in twenty-four hours; only six days per annum when it equals or exceeds half an inch in twenty-four hours; and only about one day per annum when the rainfall reaches or exceeds 1 inch in twenty-four hours. In order to deal with any excess of rainfall beyond the quarter of an inch in twenty-four hours, rain-water outlets have been provided so that when the sewers become overfilled they discharge their contents at various places into the natural outfalls. In cases in which it is intended to admit rainfall into sewers, the proportionate amount to be contributed by storms will differ in different districts, and the engineer will have to use a considerable degree of discretion in the matter; but correct results can only be arrived at after considerable experience and long observation. The following Table will be found convenient for use in making calculations as to the amount of rain falling upon the side of a drainage area:—

Rain-water outlets.

Contributio storm-water sewers.

TABLE No. 4.—Showing the QUANTITY of RAINFALL per ACRE. Table No. 4

| Inches in Depth of Rain. | Cube Feet per Acre. | Gallons per Acre. | Inches in Depth of Rain. | Cube Feet per Acre. | Gallons per Acre. |
|---|---|---|---|---|---|
| ·1 | 363 | 2,262 | ·6 | 2178 | 13,573 |
| ·15 | 544·5 | 3,393 | ·65 | 2359·5 | 14,704 |
| ·2 | 726 | 4,524 | ·7 | 2541 | 15,836 |
| ·25 | 907·5 | 5,656 | ·75 | 2722·5 | 16,967 |
| ·3 | 1089 | 6,787 | ·8 | 2904 | 18,098 |
| ·35 | 1270·5 | 7,918 | ·85 | 3085·5 | 19,309 |
| ·4 | 1452 | 9,049 | ·9 | 3267 | 20,360 |
| ·45 | 1633·5 | 10,180 | ·95 | 3448·5 | 21,491 |
| ·5 | 1815 | 11,311 | 1·0 | 3630 | 22,622 |
| ·55 | 1996·5 | 12,442 | | | |

# GEOLOGICAL CHARACTER AND PHYSICAL OUTLINE OF THE DISTRICT.

Influence of geological strata on health.

The influence of geological strata upon health has from time immemorial received a certain amount of consideration, but until a very recent period the actual result of such influences was based upon very uncertain and crude opinions. Of late very precise results of the effect of geological strata on health have been compiled by Dr. Buchanan, of the Medical Department of the Privy Council. The last column of Table No. 1, page 10, shows the reduction in the death-rate from phthisis in the case of twelve towns. This saving of life is ascribed to the effect of drainage works in drying the subsoil of those places. The effects of a dry subsoil in influencing health were pointed out by Dr. Bowditch, of Massachusetts, in a pamphlet in 1862, wherein he showed that a greater number of deaths took place from phthisis when the inhabitants of a district are located upon a retentive geological formation than takes place when they are disposed on a pervious formation. Dr. Buchanan, in his researches in reference to the influence of the works of sewerage of this country on the public health, and also as to the influence of the geological character of the soil on phthisical diseases, confirms these views; moreover, he found that districts having rapidly inclined retentive geological formations have a less death-rate from phthisis than those in which the same formation is comparatively flat. He also shows that a pervious formation, saturated with fresh water, is favourable to the development of phthisical complaints, while a pervious formation, saturated with sea water, has, as in the case of some of our sea-coast towns, little or no effect in influencing phthisical disorders. This may be due to the circulation of the water in the soil, caused by the rise and fall of the tide,

Reference to Table No. 1, page 10.

Effects of dry subsoil.

Difference between saturation with fresh and sea water.

which prevents stagnation, the great enemy of life. The influence of sewerage works in draining the subsoil of a town, and thereby beneficially influencing public health, was understood by some engineers at an early period after the revival of sanitary science; for in the report upon the "City Sewers," by Messrs. Walker, Brunel, and Cubitt, dated August, 1848, we find it stated that "the first and perhaps not least important purpose of sewers, as respects health, is as under-drainage of the surrounding earth. They answer this purpose effectually and quietly, and have done it so long that their importance in this respect is apt to be overlooked." In all works of sewerage, in order to get their full benefit, it is requisite that provision should be made for the drainage of the subsoil. The mere fact of carrying out a system of sewerage, and being obliged to cut through various strata of a more or less retentive character, is naturally a means of securing to a great extent subsoil drainage; but it is not well to depend entirely upon the intersection of various geological formations, as it has been shown, from the results compiled by Dr. Buchanan, that drainage works when first brought into operation, or during their construction, have had greater effect in drying the subsoil and in reducing the rate of death arising from phthisical disorders than has been secured in after years. This may be accounted for from the fact that the drainage of the subsoil was more perfect prior to the complete consolidation of the sewer trenches than it has been subsequently. In designing a system of sewers, therefore, the engineer should make provision — more especially in retentive geological formations — for the effectual drainage of the subsoil, the works for which purpose should be constructed and carried out so as to prevent any chance of sewer-water percolating into the surrounding ground. The mode in which this operation can be accomplished will be considered hereafter. The geological character

Benefits of sub-drainage understood by engineers.

Report of Walker, Brunel, Cubitt.

Provision should be made for sub-drainage.

Effects of drainage works in reducing subsoil water.

Provision should be made for subsoil drainage in such a way as not to allow sewage to escape.

of the district in which sewerage works are executed will also materially affect the quantity of water which may be collected from the surface of the district. In districts in which the impermeable strata covers the surface, the volume of water contributed to the sewers will be large, and be discharged more rapidly than in districts in which the geological formation is of the pervious description. On the other hand it not unfrequently happens in districts which are covered with a pervious geological formation, that a short distance below the surface subsoil water in large quantities is met with, supplying the sewers with a constant quantity of spring-water, and not unfrequently leading to difficulty in the construction of the works. The geological character of the district must also be studied, with a view to the stability of the works which are to be executed. If it is found that the geological strata is not sufficiently stable to receive the sewers, provision will have to be made whereby a good foundation for the works to be executed may be secured.

Districts in which impermeable stratum covers surface.

Districts in which pervious stratum covers surface.

Subsoil water yielded to sewers.

As a not unfrequent example of the results of sewerage works, carried out in a district of a permeable geological formation, the small town of Redhill, in Surrey, may be taken. The works of sewerage were designed by the author. The town is located on the lower greensand formation, and its population is under 5000. In carrying on the work of excavation for the sewers, more or less, in all parts of the district, subsoil water had to be contended with. In the lower portions of the district, especially, the saturation of the subsoil was so considerable, that great difficulty arose in the prosecution of the works, for, so unstable was the subsoil, that special artificial foundations for the sewers had to be adopted.* The completion of the works in a great measure removed the subsoil water; but even now, in the driest season, the springs yield not less than 25 cube feet of water per minute to the sewers.

Example of Redhill.

* See Fig. 44, page 172.

The physical outline of the district will also have a material influence upon the volume of the water which has to be conveyed by the sewers. In districts in which the gradients are steep, the discharge of surface-water takes place more rapidly than in those districts in which the same geological strata is comparatively flat, and in a district with steep gradients a larger percentage of rainfall will be contributed to the sewers than is found to be the case in districts in which the gradients are flat. The consideration of the outline of a district is of great importance, when studying the question of the ventilation of sewers; the same provisions that are effectual for the ventilation of sewers in flat districts are totally inadmissible when the gradients are great, for wherever the gradients are steep, the sewers will act as chimneys for drawing off the foul gas from the lower parts of a district, and disperse it in the higher parts, so, when the gradients are steep, special provision should be made, in order to prevent sewer gases travelling from the lower to the higher portions of a district. The mode in which this may be effected is hereafter considered at page 243.

Influence of physical outli on surface discharge.

Influence of physical outli in ventilation of sewers.

## POPULATION.

In this country, where great attention has been paid to tabulating the population of various districts, it is no difficult task for the engineer to calculate the present population of a district for which the works of sewerage are to be constructed. It may, however, become difficult to calculate the prospective population of the district, which is a point of importance, as in all works of sewerage the money expended on the works should be distributed over a term of years for repayment, and it is only just to those of the ratepayers who may hereafter occupy the district, that the works towards which they will have to contribute should be of

Present popu tion.

Prospective population.

equal service to them, as to those who called them into existence. The mode usually adopted in approximating the future population, is to ascertain what has been the prospective rate of increase for a number of years back, and by making the same, or, in some cases, a greater allowance for increase in the future, so calculate what is likely to be the probable population in years to come. In some districts this mode of estimating the population has been shown to be liable to error, as there are districts, such as manufacturing, or suburban districts, located near large centres of population, which are liable to rapid rates of increase, and in some cases the population of particular manufacturing and mining districts has been found to decline. The present population of a district can always be pretty correctly ascertained by taking the number of inhabited houses, which may be got from the rate-books, and multiplying the number by the average number of inhabitants which were found at the previous census to occupy a house. Population affects works of sewerage, inasmuch as each individual member of the community uses a certain quantity of water for ablution, and general cleansing purposes, and each individual also contributes a certain amount of manurial matter, which forms the basis of the value of the sewage of a town, so that it is absolutely necessary that the number of the population contributing to the sewers should be ascertained, and taken into consideration by the engineer, when designing works of sewerage, or sewage disposal.

How population ascertained.

How population affects works of sewerage.

## WATER-SUPPLY OF A DISTRICT.*

The works appertaining to the water-supply of a district are specially treated hereafter. Water-supply

How water-supply affects works of sewerage.

* It is the intention of the author to treat the subject of Water-Supply in a separate volume.

affects a system of sewerage to be carried out in any town, by reason of the volume of water that has to be conveyed away. The sources of supply to be taken into consideration are:—

1st. The volume of water distributed by specially constructed waterworks.

2nd. The amount raised or taken from tanks and wells on private property.

3rd. The quantity contributed by manufactories.

Average quantity of water-supply.

Taking an average of 120 towns in this country, the author found that the volume of water supplied for public purposes averaged 25 gallons per head. In some cases the quantity was greatly in excess of this average, for as much as 56 gallons per head was supplied, while in some towns it did not exceed 10 gallons per head. The quantity of water used in a district in a great measure depends upon the facilities afforded to the public in procuring the supply, also upon the sanitary appliances in operation within the district, and to some extent to the character of the population supplied with water. Districts in which water-closets are universally used, or in which the use of private baths is general, have a somewhat higher rate of water consumption than districts in which the only supply of water is from isolated stand pipes, and in which the ash-pit or some other dry system is in operation. The quantity of water supplied by pumps or other appliances procured locally from wells or tanks is generally small, for where the labour of procuring supplies of water is great, the quantity used is small; on the other hand, where facilities for procuring water are great, the consumption is found to be large. The quantity of water used by manufacturers must be considered, as provisions will generally have to be made for receiving such water into the sewers. In some processes of manufacture large quantities of water are used, which subsequently find their way to the sewers. For example,

Quantity depended upon.

Water-closets and baths increase quantity.

Quantity used by manufacturers.

TABLE No. 5.—Showing the VOLUME of SEWAGE of TOWNS.

| Name of Town. | Area of District in Acres Sewered. | Population of Sewered District. | Average Quantity of Sewage daily discharged by Sewers. Gallons. | Quantity of Sewage discharged per head per day in Gallons. | Proportionate Number of Houses supplied with Water-closets. | Remarks. |
|---|---|---|---|---|---|---|
| Alnwick and Canongate | 600 | 6,000 | 300,000 | 50 | Nearly all | |
| Bangor | 600 | 10,500 | 630,000 | 50 | ⅓ths | |
| Birmingham | 8000 | 300,000 | 15,000,000 | 50 | Very few | |
| Bishop Auckland | 290 | 5,000 | 30,000 | 6 | Very few | |
| Bury St. Edmunds | 350 | 13,000 | 50,000 | 4 | 1 per cent. | Imperfectly sewered. |
| Cardiff | 344 | 30,000 | 2,000,000 | 66 | Nearly all | |
| Carlisle | 2000 | 30,000 | 843,000 | 28 | ⅓ths | |
| Cheltenham | 2000 | 36,000 | 600,000 | 16⅔ | Nearly all | |
| Coventry | .. | 42,000 | 750,000 | 18 | 420 | |
| Crewe | .. | 16,000 | 613,000 | 38⅓ | 1¼ per cent. | With exception of about 50 water-closets, all ash-pits. |
| Croydon | 1260 | 45,000 | 3,345,000 | 76½ | All | Dry weather flow, 56 gallons per head, due to water-supply. |
| Haverfordwest | 1760 | 7,000 | 150,000 | 21½ | ½ | |
| Kelso | 100 | 4,300 | 60,000 | 14 | 10 per cent. | |
| Leek | 1280 | 10,500 | 400,000 | 38 | 1 in 30 | |
| Leicester | 1300 | 93,000 | 3,000,000 | 32¼ | 6,900 | 6 per cent., privy cesspools. |
| Liverpool | 7014 | 500,000 | 16,000,000 | 32 | Nearly all | The volume of sewage is the minimum dry weather flow. |
| London | 59,010 | 3,000,000 | 88,000,000 | 29 | w.c. general | |
| Loughborough | 380 | 10,800 | 200,000 | 18½ | 1 in 80 | |
| Luton | .. | 17,000 | 640,000 | 36·4 | 1 in 30 | |
| Merthyr Tydvil | .. | 50,000 | 850,000 | 17 | But few | Dry weather flow. |
| Nottingham | 1800 | 120,000 | 1,900,000 | 16 | ¼ | |
| Plymouth | 600 | 75,000 | 5,000,000 | 66 | Nearly all | |
| Preston | 2418 | 83,000 | 2,000,000 | 24 | 1 in 20 | Dry weather flow. |
| Redhill | .. | 3,200 | 286,000 | 89 | 50 per cent. | 200,000 gallons is spring water. |
| Rugby | 200 | 8,000 | 382,000 | 47⅞ | ⅘ths | Dry weather flow. |
| Scarborough | 884 | 23,000 | 256,000 | 11 | ⅓rds | |
| Selby | 2620 | 6,000 | 160,000 | 26 | Nearly all | |
| Sheerness | 150 | 13,000 | 310,000 | 23 | 1 per cent. | |
| Skipton | 130 | 6,000 | 116,000 | 20 | 314 | Dry weather flow. |
| Southampton | 800 | 45,000 | 2,000,000 | 44 | Nearly all | |
| Southport | 400 | 12,000 | 290,000 | 24 | About ¼ | |
| St. Helen's | 700 | 25,000 | 850,000 | 34 | 1 in 30 | |
| Taunton | 560 | 13,000 | 250,000 | 17 | 30 per cent. | |
| Wakefield | 1500 | 26,000 | 1,000,000 | 38 | 6 per cent. | |
| Warwick | .. | 10,000 | 700,000 | 70 | .. | Gaseliers manufactory at Warwick uses about 200,000 gallons of water per day. |
| Waterloo | 214 | 4,500 | 225,000 | 50 | .. | |
| Weston-super-Mare | 480 | 10,000 | 680,000 | 68 | $\frac{1}{15}$ths | |

in the town of Warwick there is a single gelatine manufactory which uses as much water in the process of manufacture as is used by the whole population of the town, upwards of 10,000, so that in this district provision had to be made for a much larger volume to pass into the sewers than would have been due under ordinary circumstances. Table No. 5 gives the volume of sewage in some towns, and will be of interest and value as a guide for future works.

## SANITARY APPLIANCES OF DISTRICT.

Complete system of sewerag

When a complete system of sewerage is intended to be carried out, and water-carriage is to be used for the removal of all the refuse and fæcal matter usually transported by sewers, the engineer will have no great difficulty in arriving at the probable volume of sewage he will have to deal with. In some places there exist differences of opinion amongst the Sewer Authorities as to the benefits derivable from the universal application of the water-carriage system. It might be supposed that when carrying out a system of sewerage in a district in which the water-closet system is intended only to be partially adopted, as is now the case in many manufacturing towns in the North of England, it would be necessary to make some abatement in the sizes of the sewers on account of the volume of sewage to be excluded. In many northern towns of this country the authorities oppose the introduction of water-closets on the ground of the increased volume of water it would be necessary to procure if their use became general. Many persons also oppose the introduction of water-closets on the ground that they are the sole cause of the pollution of the streams of the country. A very slight amount of investigation will

Differences of opinion of water-closets.

Northern towns of England, opposition to water-closets.

Midden-stead towns' sewage impure.

show that the sewage of the northern towns in which midden-steads are generally adopted, is, as a rule, quite as impure, and nearly as great in volume, as in districts in which water-closets are universally used, while at the same time the sewage contains nearly as large an amount of putrescent organic matter as in a water-closet town. The Rivers Commissioners have given the figures recorded in Table No. 6, being the result of the examination of the sewage of a large number of midden-stead and water-closet towns.

Analysis of sewage of towns.

TABLE No. 6.—Showing the COMPOSITION of the SEWAGE of TOWNS in PARTS per 100,000.

| Description. | Total Solid Matter in Solution. | Organic Carbon. | Organic Nitrogen. | Ammonia. | Total combined Nitrogen. | Chlorine. | Suspended Matters. | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Mineral. | Organic. | Total. |
| Average midden towns .. .. | 82·4 | 4·181 | 1·975 | 5·435 | 6·451 | 11·54 | 17·81 | 21·30 | 39·11 |
| Average water-closet towns .. | 72·2 | 4·696 | 2·205 | 6·703 | 7·728 | 10·66 | 24·18 | 20·51 | 44·69 |

Broadmoor sewage and earth-closets.

The excess of chlorine in the sewage of a midden-stead town shows that there is a larger proportion of urine present in a given volume of sewage than is found in a water-closet town. The Rivers Commissioners also found that the case is not substantially altered where earth-closets are used: they say "The sewage from Broadmoor Lunatic Asylum, in which these closets are partially used, exhibits no exceptional degree of weakness," and they conclude by saying, "It seems hopeless, therefore, to anticipate any substantial reduction of sewage pollution by dealing with solid excrementitious matters only."

Consumption of water due to imperfect fittings.

The great consumption of water in many towns is due rather to imperfect fittings, &c., than to the introduction of water-closets. At Croydon the author made numerous experiments, and found that for all domestic purposes, inclusive of water-closets, the

Consumption of water with perfect fittings.

average consumption of water in houses in which the fittings were perfect did not exceed five gallons per head

per day, and this result was arrived at in the case of houses which were above the average rateable value. Various devices have been proposed at different times in order to separate fæcal matter from the sewers or in some cases to separate the urine from the solid fæces. All these devices have been propounded with a view to get some money return for the agricultural constituents of the material to be dealt with, and not by any means with the view of introducing such appliances as a sanitary necessity. Table No. 5, page 38, shows the volume of sewage in various towns, the proportionate number of water-closets in use is also given, and consequently the Table in question may be taken as a guide by the engineer in carrying out similar works. To what has already been stated it is only necessary to add that the introduction of the water-closet, with perfect water-waste preventing fittings, will not materially increase the volume of sewage to be provided for, as the water used for this purpose forms but a small part of the whole of the water used for domestic and general purposes; therefore, in districts in which ash-pits, earth-closets, or other devices of this character are used for collecting fæcal matter it will be well that the same provision should be made in the size of the sewers as is made in those districts in which water-closets are universally adopted.

Separation of fæcal matter from sewers.

Separation of urine from fæces.

Agricultural not sanitary expedients.

Volume of sewage of towns.

Water-closets not materially increase water-supply.

## POSITION OF OUTFALL AND MODE OF DISPOSING OF THE SEWAGE.

The position of the outfall of the district is one of the first points that will require the consideration of the engineer, and so soon as the outfall has been arranged the rest of the scheme may be proceeded with without hesitation. In no case is it now advisable to proceed with works of internal sewerage until an outfall has

Position of outfall must be first considered.

been secured. In a great measure the success of the scheme will depend both upon the position and the number of outfalls to be brought into operation in a district. As a rule it is usual, in constructing sewers, to lay them in the direction of the natural falls of the district, consequently, the outfalls of sewers are almost invariably found to be located in the valley of a river or stream which naturally provides for the drainage. But as it is advisable that the sewage in no case should be allowed to intermix with the pure natural water of the country, so as to lead to its pollution, provision must be made for either purifying the sewage before passing it into the fresh-water streams, or, as in the case of sea-coast towns, to lead it to such a point as not to become the cause of offence. In inland towns it will be found that there are chemical or mechanical systems which will greatly palliate the evils of pollution by precipitating or deodorizing the sewage, but the nuisance arising from sewage pollution may not always be removed in this way; consequently such works are generally supplemented by intermittent filtration, or, irrigation works. The plan that has hitherto proved most successful in purifying the sewage of an inland town is that of utilizing it in its fresh state on properly prepared land. In sea-coast towns it may prove most economical to carry the sewage directly out to sea, but, as a matter of precaution, the sewage should be deodorized, or otherwise treated, before being discharged into the sea. Where sewage has to be raised artificially in order to be applied to land, as will be the case in many towns, the point of outfall will be one of material importance. In some towns a system of interception hereafter referred to, with two or more outfalls, may be advantageously introduced in order to diminish the cost of the system of sewers, and establish the economic disposal of the sewage. All outfalls should be protected by proper arrangement, so as to exclude reverse currents of either water or air from entering the sewers.

Sewers follow natural falls.

Sewage must not be passed into rivers.

Purification of sewage.

Sewage irrigation.

Sewage, sea-coast towns.

Intercepting sewers.

Outfall must be protected.

## SELF-CLEANSING SEWERS.

Construction of sewers left to unskilful workmen.

The early sewer works in this country were generally put into the hands of the most unskilful workmen. Little or no attention was paid to the proper construction of drains or sewers; in fact it appears that the fastidious generations of the past looked upon constructions that had to do with the removal of those waste matters, which have to be dealt with in every house and in every town, as too disgusting in their nature to be mentioned in the ears of refined society. The frightful consequences arising from this utter disregard to these very necessary matters became the means, in a great measure, of awakening attention, and scientific inquiry into the principles which should regulate the construction of sewers. So well is the importance of securing perfect works of sewerage now understood, that it has become a proverbial saying that "a man should look to his drains before he furnishes his drawing room." The early sewers executed in this country have been called "sewers of deposit"; in fact, at one period, it seems to have been a recognized feature that all sewers must sooner or later choke from the accumulation of deposit, therefore certain rules and regulations were laid down for their construction, with a view to make the sewers of such a size as should be convenient for the purpose of sending men into them to cleanse them when they became choked. Figs. 1, 2, and 3, represent three sizes of sewers. Those of 2 feet diameter (Fig. 1) were considered sufficient for men to crawl into in order to cleanse them; when they were from 3 feet to 3 ft. 6 in vertical dimensions, (Fig. 2) men could crouch in them, and when they were from 4 ft. to 4 ft. 6 in vertical dimensions (Fig. 3) men could move in a stooping position, and they were required to be made at last 6 feet in height, in order that men could stand in an upright position; when constructing

Causes led to improvement in construction of sewers.

Proverbial saying.

Sewers of deposit.

Rules for constructing sewers for men to enter.

Description of woodcuts.

Argument in favour of large sewers.

sewers on these principles, it was conceded that the larger sewers were made the better they were, for it was shown that if sewers were made sufficiently high for men to walk through them, a man was able to remove in the course of a few hours, from a choked sewer, as much matter as he would in as many days from a sewer of smaller dimensions. The author in the course of his experiences has often seen men pass into old sewers of no larger diameter than 2 ft. (Fig. 1), which had become

Fig. 1.

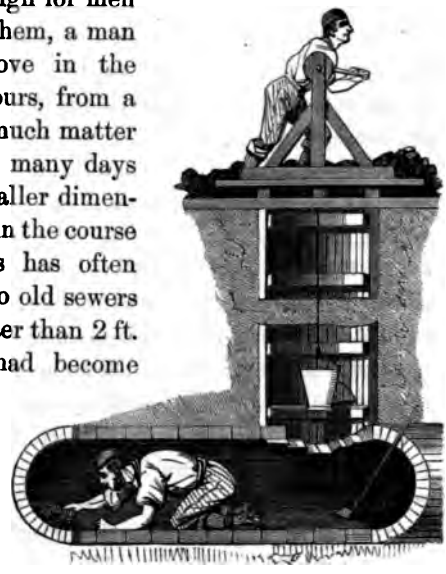
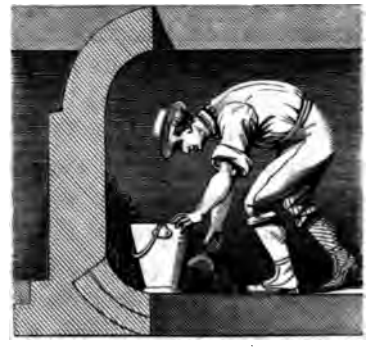


Fig. 2.

Fig. 3.



Vile character of cleansing operation.

completely choked with decomposing fæcal and other vile matter. When the noxious character of these deposits, and the nature of the work performed is fully considered, and the true principles which should

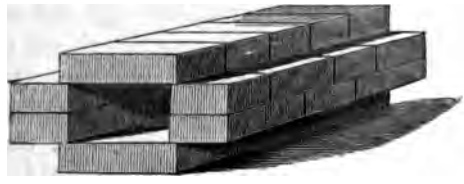
regulate the proper construction of sewers are more generally understood and appreciated, these vile practices will have an end, as there is no more necessity to send men into sewers to carry out such disgusting operations, than there is to send boys up chimneys to sweep them. The great fault in the early sewer works arose from the fact that the size, form, mode of construction, or materials adopted were not in accordance with the work the sewers had to perform. The following woodcuts represent sections of defective forms of drains and sewers. Fig. 4 is a section of a

Fault of early sewers.

Description of woodcut.

FIG. 4.

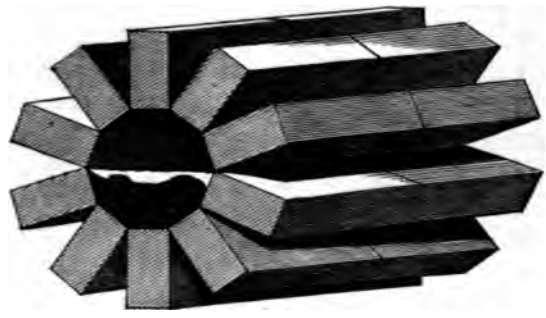
FIG. 5.



house-drain, the sides of which are constructed of bricks laid on edge on the floor of the trench, covered again with bricks lengthways, so as to give a sectional area of 6 inches by 4½ inches; such drain having nothing but a rough and often pervious soil for its floor soon became stopped up. Fig. 5 is an improvement on Fig. 4 inasmuch as bricks are also used to form the invert of the sewer. Fig. 6 represents an attempt to construct a circular sewer of small dimensions with the ordinary bricks. The effect of using such bricks in constructing so small a sewer is shown in the wide gaping

joints at the back, and as such sewers were generally put together with improper materials, in course of time

Fig. 6.



the ordinary mortar in the joints disappeared, and the liquid escaped through the joints and left the solid matter to choke the sewer.* The earlier sewers were generally made with flat inverts, in fact this was the plan adopted by the Romans, and probably copied from them. The stream of sewage flowing through the sewers was often very small in proportion to the size of the sewer, and, when spread over a large flat surface, its velocity was so much impeded by the frictional resistance of the bed, and the angles of the channel, that the matters in suspension in the water were deposited, until, at length the sewers became completely choked, and then commenced those disgusting operations of sending men into them to remove the obstructions. The following Figures, 7, 8, and 9, show the way in which matters accumulate in sewers.

Early sewers, flat inverts.

Examples compiled, General Board of Health.

Materials used in sewers.

These examples are taken from well-authenticated records compiled by the General Board of Health. The materials used in the construction of sewer works have also had some effect in promoting stoppages. Sewers constructed of rough stone or other materials presenting

* Many of the houses in the West-end of London still remain drained in this manner.

a rough and irregular surface (Fig. 10) cause an obstruction to the flow of the sewage by retarding the stream,

FIG. 7.

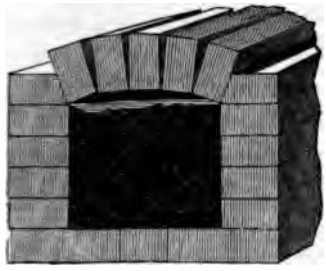


FIG. 8.

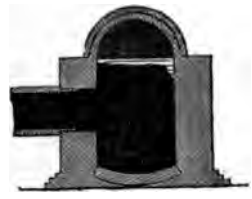
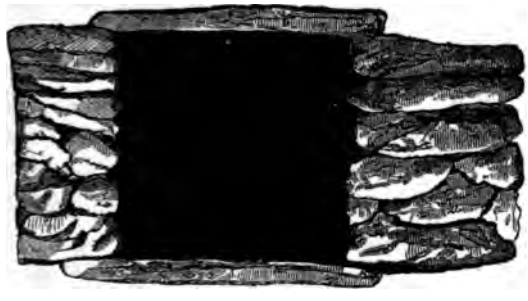


FIG. 9.

FIG. 10.



which leads to deposit. Other sewers were constructed of such an impervious character that they really became

Absorbing sewers.

absorbing sewers (*vide* Figs. 1 and 3), that is, the solid and liquid matters passed into the sewers, the liquid flowed away through the crevices and joints of the sewer itself into the subsoil, and left the solid matter to choke the sewers.

How sewers are to be made self-cleansing.

It has been amply demonstrated, from the results gained by experience in the management and working of sewers, that by so proportioning the size, form, and inclination of a sewer to the volume of sewage it has to convey, it may be made self-cleansing. It was a generally received opinion at one time that all brick sewers were sewers of deposit, and that pipe sewers were self-cleansing, but upon this point there can be no greater mistake. Pipe sewers may become sewers of deposit, and brick sewers may be made self-cleansing.

Velocity of flow to be maintained.

In order to prevent deposit in sewers, it is necessary to provide a certain velocity in the flow of sewage, which must be secured throughout the whole system of sewers, and such velocity must be sufficient to prevent the subsidence from the liquid of any matters in suspension, and also to move along the bed of the channel any solid deposit.

Experiments.

Numerous experiments have been made, at various times, by different individuals, as to the effect of currents of water in moving matter along variously formed channels, and from these experiments certain rules have been laid down for the guidance of the engineer when constructing works of sewerage.

Mr. Wicksteed's experiments.

Mr. Wicksteed ascertained, on the Leicester Sewerage Works, that if a bottom velocity of 16 inches per second, equal to $\frac{8}{10}$ths of a mile per hour, could be maintained, such velocity would prevent the deposit of small pieces of brick and stone, and with a velocity of $21\frac{1}{4}$ inches per second, or 1·24 mile per hour, iron borings or heavy slag would be removed by the current.*

* Experience in the working of sewers, since the date of these experiments, has amply demonstrated that the velocity of flow must be considerably greater than shown by Mr. Wicksteed's experiments, if sewers are to be kept free from deposit. In no case should the velocity be less than 2 ft. per second, but in the generality of cases it should be much greater.

M. Dubuat gives the velocity necessary to remove certain solid substances as under.

| | ft. | in. | |
|---|---|---|---|
| River mud, semi-fluid .. .. .. .. .. | 0 | 3 | per second. |
| Brown pottery clay .. .. .. .. .. | 0 | 3¼ | „ |
| Common clay .. .. .. .. .. .. | 0 | 6 | „ |
| Yellow sand, loamy .. .. .. .. .. | 0 | 8½ | „ |
| Common river sand .. .. .. .. .. | 1 | 0 | „ |
| Gravel, size small seeds .. .. .. .. | 0 | 4½ | „ |
| „ of peas .. .. .. .. .. | 0 | 7½ | „ |
| „ of beans .. .. .. .. .. | 1 | 0½ | „ |
| Coarse ballast .. .. .. .. .. .. | 2 | 0 | „ |
| Sea shingle, about 1 in. diameter .. .. | 2 | 2 | „ |
| Large shingle .. .. .. .. .. .. | 3 | 0 | „ |
| Angular shingle, size of hen's eggs .. .. | 3 | 3 | „ |
| Broken stones .. .. .. .. .. .. | 4 | 0 | „ |
| „ agglomerated, or schistous rocks .. | 4 | 4 | „ |
| Rocks with distinct layers .. .. .. .. | 6 | 0 | „ |
| Hard rocks .. .. .. .. .. .. .. | 10 | 0 | „ |

Mr. Beardmore, in his extremely valuable hydraulic Tables, gives the velocity which should be maintained in sewers at 150 feet per minute. Mr. J. Phillips, who had had considerable experience in the working of sewers in London, states that a velocity of 2½ feet per second, equal to 1¾ mile per hour, will prevent deposit. Professor Rankine says that the volocity in sewers should not be less than 1 foot per second or more than 4½ feet per second. House drains, he says, should have a velocity of 4½ feet per second. The velocity necessary to remove obstructions from sewers in a great measure depends on the specific gravity of the deposit. All matters submerged in water lose weight in proportion to the volume of water they displace, consequently comparatively small currents have great effect in carrying forward solid matter. Experiments made by Mr. J. E. Blackwell, C.E., for the Government referees in the plan of Main Drainage of the Metropolis, show very clearly the effect of currents in removing substances of different specific gravity. For example, coal of a specific gravity of 1·26 commenced to move in a current of from 1·25 to 1·50 foot per second. A second sample of coal of specific gravity 1·33 did not commence

Mr. Beardmor

Mr. Phillips.

Professor Rankine.

Velocity to re move obstructions depends o their specific gravity.

Mr. J. E. Blackwell's experiments.

to move until the velocity was 1·50 to 1·75 foot per second, a brickbat of specific gravity 2·0, chalk of specific gravity 2·05, required a velocity of 1·75 to 2 feet per second to start them. Oolitic stone, specific gravity 2·17; brickbat 2·12, chalk specific gravity 2·0; broken granite specific gravity 2·66, required a velocity of 2·0 to 2·25 feet per second to start them. Chalk specific gravity 2·17, brickbats specific gravity 2·18; limestone specific gravity 1·46, required a velocity of from 2·25 to 2·50 feet per second to start them. Oolite stone specific gravity 2·32, flints specific gravity 2·66, limestone specific gravity 3·00, required a velocity of 2·50 to 2·75 to start them. It was shown in these experiments that after the start of the materials with the current, in no case did the materials to be transported travel at the same rate as the stream, but in every case their progress was considerably less, as a rule often more than 50 per cent. less, than the velocity of the current. The author in the course of his experience has found that in order to prevent deposit in small sewers or drains, such as those of 6-in. and 9-in. diameter, a velocity of not less than 3 feet per second should be produced. Sewers from 12 to 24 inches diameter should have a velocity of not less than 2½ feet per second, and in sewers of larger dimensions, in no case should the velocity be less than 2 feet per second. In order to maintain these velocities in sewers, it is absolutely requisite that a certain rate of inclination should be secured; thus small sewers will require a greater rate of fall than large sewers, and large sewers, on the other hand, must have provided a much larger volume of fluid, so that the proper velocity through them may be maintained. It is not sufficient to design a large sewer in a district of small fall unless to prevent its becoming a sewer of deposit, (which it would undoubtedly become even when its rate of inclination when running full or half full would give the required velocity to make it self-cleansing,) we are sure of a volume of sewage which will fill

Materials transported do not move with same velocity as the current.

Author's experience.

Sufficient volume of sewage is necessary to render sewers self-cleansing.

the sewer to the proper extent so as to maintain the velocity required, either naturally, or artificially by flushing arrangements. Sewers of various sizes, having different rates of inclination, will have the same velocity: for example, a sewer 10 feet diameter having a fall of 2 feet per mile, a sewer 5 feet diameter with a fall of 4 feet per mile, a sewer 2 feet diameter having a fall of 10 feet per mile, and a sewer 1 foot diameter and a fall of 20 feet per mile, but in order to maintain the same velocity the 10-feet sewer will require to convey one hundred times, the 5-feet twenty-five times, and the 2-feet four times as much sewage as the 1-foot sewer. The adjustment of the various sizes of sewers is a matter which will always require the careful consideration of the engineer.

Sewers of various sizes have same velocity.

Hitherto, in speaking of velocities, we have been dealing with the mean velocity of streams, but in practice it is found that velocity increases in a current as the fluid particles of the stream are removed from its sides or bed, consequently the velocity at the bottom of a channel, or over the invert of a sewer, is the velocity which is really effective in scouring it, and such velocity is always less than the mean velocity. The mean velocity of the stream, according to M. Prony's formula, is as follows:—

Bottom velocity in sewers.

M. Prony's formula.

$$v = V \frac{V + 7{\cdot}776}{V + 10{\cdot}335}.$$

V = Surface velocity,
$v$ = Mean ,,

For all practical purposes in the case of sewers, the velocity along the invert of the sewer will be $\frac{2}{3}$ths of the surface velocity, or $\frac{8}{10}$ths of the mean velocity given in the Tables. The velocity in a sewer is proportionate to the square root of the section when divided by the wetted perimeter, therefore velocity diminishes greatly with the depth of the stream flowing through the sewers, and, as a rule, when we have the smallest quantity of sewage and the least depth flowing through

Rule for bottom velocity in sewers.

the sewers, the sewage is carrying its maximum load of suspended matter, consequently there is a greater inclination for matter to subside at such times, on account of the velocity being at its minimum. In every system of sewers the upper portions should naturally have a greater rate of inclination than the lower portions of the system, as in those parts there is a smaller quantity of sewage to deal with, and consequently a greater fall is required to produce the necessary velocity to render the sewer self-cleansing. In cases in which the ordinary flow of sewage would not give the requisite velocity to render the sewers of a district self-cleansing, artificial means are used for flushing the sewers by temporarily increasing the volume passed through them in a given time. The various modes which are adopted for flushing sewers, are hereafter specially considered.

Sewers in upper district.

Necessity for flushing sewers.

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## DESCRIPTION OF TABLES RELATING TO THE VELOCITIES IN SEWERS NOS. 7 TO 18 INCLUSIVE.

These Tables are worked out from the formulæ of Weisbach, hereafter given at page 74.

Table No. 7.

Table No. 7 shows the proper inclination of various-sized sewers from 4 inches to 10 feet diameter for velocities varying from 2 feet to 6 feet per second. It is equally applicable to sewers running full or half full. In this Table it is calculated that the head of water is equal to the velocity in feet, therefore the velocity in feet multiplied by the inclination, equals the length of sewer in feet, to which the calculation applies. For example, a drain 4 inches diameter is required to be laid at such inclination as to give a velocity of 3 feet per second. On examination of the Table it will be seen, under the column of velocity for 3 feet, that a 4-inch sewer must have an inclination of 1 in 92, therefore, to make the calculation strictly correct, $3 \times 92 = 276$ feet, is the length of the drain to which the

calculation applies. If the velocity is 6 feet per second, the rate of inclination given by the Table would be 1 in 24, and $6 \times 24 = 144$ feet, the length to which this calculation correctly applies.

Table No. 8. Table No. 8 shows the proper inclination of egg-shaped sewers for velocities varying from 2 feet to 6 feet per second when flowing full. In this Table it is calculated that the head of water is taken the same as in the previous Table, or equal to the velocity; consequently the length of sewer to which the Table is applicable, equals the velocity multiplied by the rate of inclination. For example, a sewer 3 ft. $\times$ 4 ft. 6 in., having a velocity of 2 feet per second, would require to be laid at an inclination of 1 in 2028, and the length of sewer to which the calculation is applicable $= 2 \times 2028$, or 4056 feet.

Table No. 9. Table No. 9 shows the proper inclination of egg-shaped sewers for velocities varying from 2 feet to 6 feet when flowing two-thirds full.

Table No. 10. Table No. 10 shows the proper inclination of egg-shaped sewers for velocities varying from 2 feet to 6 feet when the sewers are running one-third full. It will be seen by comparing Table No. 9 with Tables Nos. 8 or 10 that when a sewer is running two-thirds full, with a given rate of inclination, a greater velocity is produced than when the same sewer is running full or one-third full, or, in other words, it requires less inclination to produce the same velocity in a sewer when running two-thirds full, than is required to produce the same velocity in the same sewer when running full or one-third full.

Note to Tables Nos. 8, 9, and 10.

Table No. 11. Table No. 11 shows the proper inclination of circular sewers of one foot diameter when running full or half full, and working under various heads. The proper inclination of any other sized circular sewer may be found by multiplying the inclination given in this Table by the diameter of the sewer in feet or decimal parts of feet. Therefore, as we have already laid down the rule that in no sewers should the velocity be less than 2 feet

per second, the least inclination of any sewer may be approximately arrived at by multiplying the number 583 by the diameter in feet, or decimal parts in feet, of the proposed sewer. So with any other velocity, if the figures given in this Table are kept in mind, the rate of inclination for any other sized sewer may be easily ascertained. For example, take a sewer 6 inches diameter with a velocity of 2 feet, we shall find that $\cdot 5 \times 583 = 291 \cdot 5$, gives the least rate of inclination at which a sewer of that diameter should be laid down, or 1 in 291. If we take a sewer 10 feet diameter, with a velocity of 2 feet, $10 \times 583$ gives 5830, representing the least inclination of a sewer of that size, or 1 in 5830, and so on in regard to any other size. This Table is applicable to any length of sewer. In using it, all that is required to be determined is the total fall in the sewer we propose to construct. For example, say that it is 10 feet, under column $h$ we find 10 feet, and under the column of velocity, say 2 feet, we find $606 \cdot 3$, which represents the least inclination of a sewer of one foot diameter. If the sewer was 3 feet diameter, the proper rate of inclination to give a velocity of 2 feet per second, would be $3 \times 606 \cdot 3 = 1$ in 1819, or if the sewer was 18 inches diameter, and the velocity required 3 feet per second, we shall find opposite the 10 feet fall in the column of 3 feet velocities, $289 \cdot 3$, which multiplied by $1 \cdot 5$ foot $= 1$ in 434.

Table No. 12. Table No. 12 shows the proper inclination of egg-shaped sewers 1 ft. $\times$ 1 ft. 6 in. when running full and working under various heads. The proper inclination of any other sized egg-shaped sewer may be easily ascertained from this Table, for it will be found that if the least or transverse diameter in feet or decimal parts of feet is multiplied by the inclination given under the several velocities in this Table, the result will express the proper inclination for any other sized sewer having the usual proportions,* that is, in cases in which the transverse diameter equals two-thirds that of the vertical

* The proportion is shown in Fig. 16, p. 100.

diameter, the invert being struck with a radius of one-fourth the transverse diameter of the sewer, the side being struck with a radius equal to the vertical dimensions of the sewer. For example, if we take a sewer 3 ft. × 4 ft. 6 in., the total fall in the length of sewer taken into consideration being 10 feet, the velocity requisite to be maintained in the sewer when running full being 2 feet per second, we shall find under column of 2 feet velocities opposite 10 feet, 702·6; if we multiply this by 3 feet, or the transverse diameter of the sewer in question, it will correctly express the inclination of the required sewer, or $3 \times 702 \cdot 6 = 1$ in 2107·8.

Table No. 13. Table No. 13 is similar to No. 12, except that it is calculated to give the inclination and velocity of sewers when running two-thirds full.

Table No. 14. Table No. 14 is similar to No. 12, except that it is calculated to give the inclination and velocity of sewers when running one-third full.

Table No. 15. Table No. 15 gives the velocity in feet per minute in circular sewers of sizes varying from 4 inches to 10 feet diameter when constructed at inclinations varying from 1 in 50 to 1 in 6000. In preparing this Table, the length of sewer taken into consideration is the same as in Table No. 7, or the head of water is taken as being equal to the velocity. For all practical purposes it may be considered correct, but in cases in which greater accuracy is required, the proper inclinations may be worked out from Table No. 11.

Table No. 16. Table No. 16 gives the velocity in feet per minute of egg-shaped sewers when running full. It is calculated for sewers varying in size from 1 ft. × 1 ft. 6 in. to 6 ft. × 9 ft., when constructed at inclinations varying from 1 in 100 to 1 in 4000.

Table No. 17. Table No. 17 is similar to Table No. 16, except that the calculations are made for sewers when running two-thirds full.

Table No. 18. Table No. 18 is similar to Table No. 16, except that the calculations are made for sewers when running one-third full.

TABLE No. 7.—Showing the PROPER INCLINATION of CIRCULAR SEWERS, for Velocities varying from 2 feet to 6 feet per second, when running full or half full.

| Diameter in Inches. | RATE OF INCLINATION FOR | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $v = 2$. | $v = 2{\cdot}5$. | $v = 3$. | $v = 3{\cdot}5$. | $v = 4$. | $v = 4{\cdot}5$. | $v = 5$. | $v = 5{\cdot}5$. | $v = 6$. |
| 4 | 1 in 194 | 1 in 129 | 1 in 92 | 1 in 68 | 1 in 53 | 1 in 42 | 1 in 34 | 1 in 29 | 1 in 24 |
| 6 | „ 292 | „ 193 | „ 137 | „ 102 | „ 80 | „ 63 | „ 51 | „ 43 | „ 36 |
| 8 | „ 389 | „ 257 | „ 183 | „ 137 | „ 106 | „ 85 | „ 69 | „ 57 | „ 48 |
| 9 | „ 437 | „ 290 | „ 206 | „ 154 | „ 119 | „ 95 | „ 77 | „ 65 | „ 54 |
| 10 | „ 486 | „ 322 | „ 229 | „ 171 | „ 133 | „ 106 | „ 86 | „ 72 | „ 60 |
| 12 | „ 583 | „ 386 | „ 275 | „ 205 | „ 159 | „ 127 | „ 103 | „ 86 | „ 72 |
| 15 | „ 729 | „ 482 | „ 344 | „ 256 | „ 199 | „ 159 | „ 129 | „ 107 | „ 90 |
| 18 | „ 875 | „ 579 | „ 412 | „ 307 | „ 239 | „ 190 | „ 154 | „ 129 | „ 108 |
| 20 | „ 972 | „ 643 | „ 458 | „ 342 | „ 265 | „ 212 | „ 172 | „ 143 | „ 120 |
| 22 | „ 1069 | „ 708 | „ 504 | „ 376 | „ 292 | „ 233 | „ 189 | „ 158 | „ 132 |
| 24 | „ 1166 | „ 772 | „ 550 | „ 410 | „ 318 | „ 254 | „ 206 | „ 172 | „ 144 |
| 30 | „ 1458 | „ 965 | „ 687 | „ 512 | „ 398 | „ 317 | „ 257 | „ 215 | „ 180 |
| 36 | „ 1749 | „ 1158 | „ 825 | „ 615 | „ 477 | „ 381 | „ 309 | „ 258 | „ 216 |
| 40 | „ 1944 | „ 1286 | „ 917 | „ 683 | „ 530 | „ 423 | „ 343 | „ 287 | „ 240 |
| 45 | „ 2186 | „ 1448 | „ 1031 | „ 769 | „ 596 | „ 476 | „ 386 | „ 323 | „ 270 |
| 48 | „ 2332 | „ 1544 | „ 1100 | „ 820 | „ 636 | „ 508 | „ 412 | „ 344 | „ 288 |
| 54 | „ 2624 | „ 1737 | „ 1237 | „ 922 | „ 716 | „ 571 | „ 463 | „ 387 | „ 324 |
| 60 | „ 2915 | „ 1930 | „ 1375 | „ 1025 | „ 795 | „ 635 | „ 515 | „ 430 | „ 360 |
| 66 | „ 3207 | „ 2123 | „ 1512 | „ 1127 | „ 875 | „ 698 | „ 566 | „ 473 | „ 396 |
| 72 | „ 3498 | „ 2316 | „ 1650 | „ 1230 | „ 954 | „ 762 | „ 618 | „ 516 | „ 432 |
| 78 | „ 3790 | „ 2509 | „ 1787 | „ 1332 | „ 1034 | „ 825 | „ 669 | „ 559 | „ 468 |
| 84 | „ 4081 | „ 2702 | „ 1925 | „ 1435 | „ 1113 | „ 889 | „ 721 | „ 602 | „ 504 |
| 90 | „ 4373 | „ 2895 | „ 2062 | „ 1537 | „ 1193 | „ 952 | „ 772 | „ 645 | „ 540 |
| 96 | „ 4664 | „ 3088 | „ 2200 | „ 1640 | „ 1272 | „ 1016 | „ 824 | „ 688 | „ 576 |
| 102 | „ 4956 | „ 3281 | „ 2337 | „ 1742 | „ 1352 | „ 1079 | „ 875 | „ 731 | „ 612 |
| 108 | „ 5247 | „ 3474 | „ 2475 | „ 1845 | „ 1431 | „ 1143 | „ 927 | „ 774 | „ 648 |
| 114 | „ 5539 | „ 3667 | „ 2612 | „ 1947 | „ 1511 | „ 1206 | „ 978 | „ 817 | „ 684 |
| 120 | „ 5830 | „ 3860 | „ 2750 | „ 2050 | „ 1590 | „ 1270 | „ 1030 | „ 860 | „ 720 |

**TABLE No. 8.—Showing the PROPER INCLINATION of EGG-SHAPED SEWERS, for Velocities varying from 2 feet to 6 feet per second, when running full.**

| Size of Sewer. | $v = 2$. | $v = 2{\cdot}5$. | $v = 3$. | $v = 3{\cdot}5$. | $v = 4$. | $v = 4{\cdot}5$ | $v = 5$. | $v = 5{\cdot}5$ | $v = 6$. |
|---|---|---|---|---|---|---|---|---|---|
| ′ ″ ′ ″ | | | | | | | | | |
| 1 0 × 1 6 | 1 in 676 | 1 in 448 | 1 in 318 | 1 in 238 | 1 in 185 | 1 in 147 | 1 in 120 | 1 in 100 | 1 in 84 |
| 1 2 × 1 9 | ,, 789 | ,, 523 | ,, 371 | ,, 277 | ,, 216 | ,, 171 | ,, 140 | ,, 117 | ,, 98 |
| 1 4 × 2 0 | ,, 902 | ,, 597 | ,, 424 | ,, 317 | ,, 247 | ,, 196 | ,, 160 | ,, 133 | ,, 112 |
| 1 6 × 2 3 | ,, 1014 | ,, 672 | ,, 477 | ,, 357 | ,, 278 | ,, 220 | ,, 180 | ,, 150 | ,, 126 |
| 1 8 × 2 6 | ,, 1127 | ,, 747 | ,, 530 | ,, 397 | ,, 308 | ,, 245 | ,, 200 | ,, 167 | ,, 140 |
| 1 10 × 2 9 | ,, 1239 | ,, 821 | ,, 583 | ,, 436 | ,, 339 | ,, 269 | ,, 220 | ,, 183 | ,, 154 |
| 2 0 × 3 0 | ,, 1352 | ,, 896 | ,, 636 | ,, 476 | ,, 370 | ,, 294 | ,, 240 | ,, 200 | ,, 168 |
| 2 2 × 3 3 | ,, 1465 | ,, 971 | ,, 689 | ,, 515 | ,, 401 | ,, 318 | ,, 260 | ,, 217 | ,, 182 |
| 2 4 × 3 6 | ,, 1578 | ,, 1045 | ,, 742 | ,, 555 | ,, 432 | ,, 343 | ,, 280 | ,, 233 | ,, 196 |
| 2 6 × 3 9 | ,, 1690 | ,, 1120 | ,, 795 | ,, 595 | ,, 463 | ,, 367 | ,, 300 | ,, 250 | ,, 210 |
| 2 8 × 4 0 | ,, 1803 | ,, 1195 | ,, 848 | ,, 635 | ,, 493 | ,, 392 | ,, 320 | ,, 267 | ,, 224 |
| 2 10 × 4 3 | ,, 1915 | ,, 1269 | ,, 901 | ,, 674 | ,, 524 | ,, 416 | ,, 340 | ,, 283 | ,, 238 |
| 3 0 × 4 6 | ,, 2028 | ,, 1344 | ,, 954 | ,, 714 | ,, 555 | ,, 441 | ,, 360 | ,, 300 | ,, 252 |
| 3 2 × 4 9 | ,, 2141 | ,, 1419 | ,, 1007 | ,, 753 | ,, 586 | ,, 465 | ,, 380 | ,, 317 | ,, 266 |
| 3 4 × 5 0 | ,, 2254 | ,, 1493 | ,, 1060 | ,, 793 | ,, 617 | ,, 490 | ,, 400 | ,, 333 | ,, 280 |
| 3 6 × 5 3 | ,, 2366 | ,, 1568 | ,, 1113 | ,, 833 | ,, 648 | ,, 514 | ,, 420 | ,, 350 | ,, 294 |
| 3 8 × 5 6 | ,, 2479 | ,, 1643 | ,, 1166 | ,, 873 | ,, 678 | ,, 539 | ,, 440 | ,, 367 | ,, 308 |
| 3 10 × 5 9 | ,, 2591 | ,, 1717 | ,, 1219 | ,, 912 | ,, 709 | ,, 563 | ,, 460 | ,, 383 | ,, 322 |
| 4 0 × 6 0 | ,, 2704 | ,, 1792 | ,, 1272 | ,, 952 | ,, 740 | ,, 588 | ,, 480 | ,, 400 | ,, 336 |
| 4 2 × 6 3 | ,, 2817 | ,, 1867 | ,, 1325 | ,, 991 | ,, 771 | ,, 612 | ,, 500 | ,, 417 | ,, 350 |
| 4 4 × 6 6 | ,, 2930 | ,, 1941 | ,, 1378 | ,, 1031 | ,, 802 | ,, 637 | ,, 520 | ,, 433 | ,, 364 |
| 4 6 × 6 9 | ,, 3042 | ,, 2016 | ,, 1431 | ,, 1071 | ,, 833 | ,, 661 | ,, 540 | ,, 450 | ,, 378 |
| 4 8 × 7 0 | ,, 3155 | ,, 2091 | ,, 1484 | ,, 1111 | ,, 863 | ,, 686 | ,, 560 | ,, 467 | ,, 392 |
| 4 10 × 7 3 | ,, 3267 | ,, 2165 | ,, 1537 | ,, 1150 | ,, 894 | ,, 710 | ,, 580 | ,, 483 | ,, 406 |
| 5 0 × 7 6 | ,, 3380 | ,, 2240 | ,, 1590 | ,, 1190 | ,, 925 | ,, 735 | ,, 600 | ,, 500 | ,, 420 |
| 5 2 × 7 9 | ,, 3493 | ,, 2315 | ,, 1643 | ,, 1229 | ,, 956 | ,, 759 | ,, 620 | ,, 517 | ,, 434 |
| 5 4 × 8 0 | ,, 3606 | ,, 2389 | ,, 1696 | ,, 1269 | ,, 987 | ,, 784 | ,, 640 | ,, 533 | ,, 448 |
| 5 6 × 8 3 | ,, 3718 | ,, 2464 | ,, 1749 | ,, 1309 | ,, 1018 | ,, 808 | ,, 660 | ,, 550 | ,, 462 |
| 5 8 × 8 6 | ,, 3831 | ,, 2539 | ,, 1802 | ,, 1349 | ,, 1048 | ,, 833 | ,, 680 | ,, 567 | ,, 476 |
| 5 10 × 8 9 | ,, 3943 | ,, 2613 | ,, 1855 | ,, 1388 | ,, 1079 | ,, 857 | ,, 700 | ,, 583 | ,, 490 |
| 6 0 × 9 0 | ,, 4056 | ,, 2688 | ,, 1908 | ,, 1428 | ,, 1110 | ,, 882 | ,, 720 | ,, 600 | ,, 504 |

TABLE No. 9.—Showing the PROPER INCLINATION of EGG-SHAPED SEWERS, for Velocities varying from 2 feet to 6 feet per second, when running two-thirds full.

| Size of Sewer. | v = 2. | v = 2·5. | v = 3. | v = 3·5. | v = 4. | v = 4·5. | v = 5. | v = 5·5. | v = 6. |
|---|---|---|---|---|---|---|---|---|---|
| ′ ″ ′ ″ | | | | | | | | | |
| 1 0 × 1 6 | 1 in 737 | 1 in 488 | 1 in 347 | 1 in 259 | 1 in 201 | 1 in 160 | 1 in 131 | 1 in 108 | 1 in 91 |
| 1 2 × 1 9 | ,, 860 | ,, 569 | ,, 405 | ,, 302 | ,, 234 | ,, 187 | ,, 153 | ,, 126 | ,, 106 |
| 1 4 × 2 0 | ,, 983 | ,, 651 | ,, 463 | ,, 345 | ,, 268 | ,, 213 | ,, 175 | ,, 144 | ,, 121 |
| 1 6 × 2 3 | ,, 1105 | ,, 732 | ,, 520 | ,, 388 | ,, 301 | ,, 240 | ,, 196 | ,, 162 | ,, 137 |
| 1 8 × 2 6 | ,, 1228 | ,, 813 | ,, 578 | ,, 432 | ,, 335 | ,, 267 | ,, 218 | ,, 180 | ,, 152 |
| 1 10 × 2 9 | ,, 1351 | ,, 895 | ,, 636 | ,, 475 | ,, 368 | ,, 293 | ,, 240 | ,, 198 | ,, 167 |
| 2 0 × 3 0 | ,, 1474 | ,, 976 | ,, 694 | ,, 518 | ,, 402 | ,, 320 | ,, 262 | ,, 216 | ,, 182 |
| 2 2 × 3 3 | ,, 1597 | ,, 1057 | ,, 752 | ,, 561 | ,, 435 | ,, 347 | ,, 284 | ,, 234 | ,, 197 |
| 2 4 × 3 6 | ,, 1720 | ,, 1139 | ,, 810 | ,, 604 | ,, 469 | ,, 373 | ,, 306 | ,, 252 | ,, 212 |
| 2 6 × 3 9 | ,, 1842 | ,, 1220 | ,, 867 | ,, 647 | ,, 502 | ,, 400 | ,, 327 | ,, 270 | ,, 228 |
| 2 8 × 4 0 | ,, 1965 | ,, 1301 | ,, 925 | ,, 691 | ,, 536 | ,, 427 | ,, 349 | ,, 288 | ,, 243 |
| 2 10 × 4 3 | ,, 2088 | ,, 1382 | ,, 983 | ,, 734 | ,, 569 | ,, 453 | ,, 371 | ,, 306 | ,, 258 |
| 3 0 × 4 6 | ,, 2211 | ,, 1464 | ,, 1041 | ,, 777 | ,, 603 | ,, 480 | ,, 393 | ,, 324 | ,, 273 |
| 3 2 × 4 9 | ,, 2334 | ,, 1545 | ,, 1099 | ,, 820 | ,, 636 | ,, 507 | ,, 415 | ,, 342 | ,, 288 |
| 3 4 × 5 0 | ,, 2457 | ,, 1627 | ,, 1157 | ,, 863 | ,, 670 | ,, 533 | ,, 437 | ,, 360 | ,, 303 |
| 3 6 × 5 3 | ,, 2579 | ,, 1708 | ,, 1214 | ,, 906 | ,, 703 | ,, 560 | ,, 458 | ,, 378 | ,, 319 |
| 3 8 × 5 6 | ,, 2702 | ,, 1789 | ,, 1272 | ,, 950 | ,, 737 | ,, 587 | ,, 480 | ,, 396 | ,, 334 |
| 3 10 × 5 9 | ,, 2825 | ,, 1871 | ,, 1330 | ,, 993 | ,, 770 | ,, 613 | ,, 502 | ,, 414 | ,, 349 |
| 4 0 × 6 0 | ,, 2948 | ,, 1952 | ,, 1388 | ,, 1036 | ,, 804 | ,, 640 | ,, 524 | ,, 432 | ,, 364 |
| 4 2 × 6 3 | ,, 3071 | ,, 2033 | ,, 1446 | ,, 1079 | ,, 837 | ,, 667 | ,, 546 | ,, 450 | ,, 379 |
| 4 4 × 6 6 | ,, 3194 | ,, 2115 | ,, 1504 | ,, 1122 | ,, 871 | ,, 693 | ,, 568 | ,, 468 | ,, 394 |
| 4 6 × 6 9 | ,, 3316 | ,, 2196 | ,, 1561 | ,, 1165 | ,, 904 | ,, 720 | ,, 589 | ,, 486 | ,, 410 |
| 4 8 × 7 0 | ,, 3439 | ,, 2277 | ,, 1619 | ,, 1209 | ,, 938 | ,, 747 | ,, 611 | ,, 504 | ,, 425 |
| 4 10 × 7 3 | ,, 3562 | ,, 2359 | ,, 1677 | ,, 1252 | ,, 971 | ,, 773 | ,, 633 | ,, 522 | ,, 440 |
| 5 0 × 7 6 | ,, 3685 | ,, 2440 | ,, 1735 | ,, 1295 | ,, 1005 | ,, 800 | ,, 655 | ,, 540 | ,, 455 |
| 5 2 × 7 9 | ,, 3808 | ,, 2521 | ,, 1793 | ,, 1338 | ,, 1038 | ,, 827 | ,, 677 | ,, 558 | ,, 470 |
| 5 4 × 8 0 | ,, 3931 | ,, 2603 | ,, 1851 | ,, 1381 | ,, 1072 | ,, 853 | ,, 699 | ,, 576 | ,, 485 |
| 5 6 × 8 3 | ,, 4053 | ,, 2684 | ,, 1908 | ,, 1424 | ,, 1105 | ,, 880 | ,, 720 | ,, 594 | ,, 501 |
| 5 8 × 8 6 | ,, 4176 | ,, 2765 | ,, 1966 | ,, 1468 | ,, 1139 | ,, 907 | ,, 742 | ,, 612 | ,, 516 |
| 5 10 × 8 9 | ,, 4299 | ,, 2847 | ,, 2024 | ,, 1511 | ,, 1172 | ,, 933 | ,, 764 | ,, 630 | ,, 531 |
| 6 0 × 9 0 | ,, 4422 | ,, 2928 | ,, 2082 | ,, 1554 | ,, 1206 | ,, 960 | ,, 786 | ,, 648 | ,, 546 |

**TABLE No. 10.**—Showing the **PROPER INCLINATION** of **EGG-SHAPED SEWERS**, for Velocities varying from 2 feet to 6 feet per second, when running one-third full.

| Size of Sewer. | $v = 2$. | $v = 2{\cdot}5$. | $v = 3$. | $v = 3{\cdot}5$. | $v = 4$. | $v = 4{\cdot}5$. | $v = 5$. | $v = 5{\cdot}5$. | $v = 6$. |
|---|---|---|---|---|---|---|---|---|---|
| ′ ″ × ′ ″ | | | | | | | | | |
| 1 0 × 1 6 | 1 in 482 | 1 in 319 | 1 in 227 | 1 in 170 | 1 in 132 | 1 in 105 | 1 in 85 | 1 in 71 | 1 in 60 |
| 1 2 × 1 9 | „ 562 | „ 372 | „ 265 | „ 198 | „ 154 | „ 122 | „ 99 | „ 83 | „ 70 |
| 1 4 × 2 0 | „ 643 | „ 425 | „ 303 | „ 227 | „ 176 | „ 140 | „ 113 | „ 95 | „ 80 |
| 1 6 × 2 3 | „ 723 | „ 478 | „ 340 | „ 255 | „ 198 | „ 157 | „ 127 | „ 106 | „ 90 |
| 1 8 × 2 6 | „ 803 | „ 532 | „ 378 | „ 283 | „ 220 | „ 175 | „ 142 | „ 118 | „ 100 |
| 1 10 × 2 9 | „ 884 | „ 585 | „ 416 | „ 312 | „ 242 | „ 192 | „ 156 | „ 130 | „ 110 |
| 2 0 × 3 0 | „ 964 | „ 638 | „ 454 | „ 340 | „ 264 | „ 210 | „ 170 | „ 142 | „ 120 |
| 2 2 × 3 3 | „ 1044 | „ 691 | „ 492 | „ 368 | „ 286 | „ 227 | „ 184 | „ 154 | „ 130 |
| 2 4 × 3 6 | „ 1125 | „ 744 | „ 530 | „ 397 | „ 308 | „ 245 | „ 198 | „ 166 | „ 140 |
| 2 6 × 3 9 | „ 1205 | „ 797 | „ 567 | „ 425 | „ 330 | „ 262 | „ 212 | „ 177 | „ 150 |
| 2 8 × 4 0 | „ 1285 | „ 851 | „ 605 | „ 453 | „ 352 | „ 280 | „ 227 | „ 189 | „ 160 |
| 2 10 × 4 3 | „ 1366 | „ 904 | „ 643 | „ 482 | „ 374 | „ 297 | „ 241 | „ 201 | „ 170 |
| 3 0 × 4 6 | „ 1446 | „ 957 | „ 681 | „ 510 | „ 396 | „ 315 | „ 255 | „ 213 | „ 180 |
| 3 2 × 4 9 | „ 1526 | „ 1010 | „ 719 | „ 538 | „ 418 | „ 332 | „ 269 | „ 225 | „ 190 |
| 3 4 × 5 0 | „ 1607 | „ 1063 | „ 757 | „ 567 | „ 440 | „ 350 | „ 283 | „ 237 | „ 200 |
| 3 6 × 5 3 | „ 1687 | „ 1116 | „ 794 | „ 595 | „ 462 | „ 367 | „ 297 | „ 248 | „ 210 |
| 3 8 × 5 6 | „ 1767 | „ 1170 | „ 832 | „ 623 | „ 484 | „ 385 | „ 312 | „ 260 | „ 220 |
| 3 10 × 5 9 | „ 1848 | „ 1223 | „ 870 | „ 652 | „ 506 | „ 402 | „ 326 | „ 272 | „ 230 |
| 4 0 × 6 0 | „ 1928 | „ 1276 | „ 908 | „ 680 | „ 528 | „ 420 | „ 340 | „ 284 | „ 240 |
| 4 2 × 6 3 | „ 2008 | „ 1329 | „ 946 | „ 708 | „ 550 | „ 437 | „ 354 | „ 296 | „ 250 |
| 4 4 × 6 6 | „ 2089 | „ 1382 | „ 984 | „ 737 | „ 572 | „ 455 | „ 368 | „ 308 | „ 260 |
| 4 6 × 6 9 | „ 2169 | „ 1435 | „ 1021 | „ 765 | „ 594 | „ 472 | „ 382 | „ 319 | „ 270 |
| 4 8 × 7 0 | „ 2249 | „ 1489 | „ 1059 | „ 793 | „ 616 | „ 490 | „ 397 | „ 331 | „ 280 |
| 4 10 × 7 3 | „ 2330 | „ 1542 | „ 1097 | „ 822 | „ 638 | „ 507 | „ 411 | „ 343 | „ 290 |
| 5 0 × 7 6 | „ 2410 | „ 1595 | „ 1135 | „ 850 | „ 660 | „ 525 | „ 425 | „ 355 | „ 300 |
| 5 2 × 7 9 | „ 2490 | „ 1648 | „ 1173 | „ 878 | „ 682 | „ 542 | „ 439 | „ 367 | „ 310 |
| 5 4 × 8 0 | „ 2571 | „ 1701 | „ 1211 | „ 907 | „ 704 | „ 560 | „ 453 | „ 379 | „ 320 |
| 5 6 × 8 3 | „ 2651 | „ 1754 | „ 1248 | „ 935 | „ 726 | „ 577 | „ 467 | „ 390 | „ 330 |
| 5 8 × 8 6 | „ 2731 | „ 1808 | „ 1286 | „ 963 | „ 748 | „ 595 | „ 482 | „ 402 | „ 340 |
| 5 10 × 8 9 | „ 2812 | „ 1861 | „ 1324 | „ 992 | „ 770 | „ 612 | „ 496 | „ 414 | „ 350 |
| 6 0 × 9 0 | „ 2892 | „ 1914 | „ 1362 | „ 1020 | „ 792 | „ 630 | „ 510 | „ 426 | „ 360 |

TABLE No. 11.—Showing the PROPER INCLINATION of CIRCULAR SEWERS, 1 foot diameter, when running full or half full and working under various heads.

The proper inclination of any other sized circular sewer may be found by multiplying the inclination given in this Table by the diameter of the sewer in feet and decimal parts of feet.

| h = | v = 2. | v = 2·5. | v = 3. | v = 3·5. | v = 4. | v = 4·5. | v = 5. | v = 5·5 | v = 6. | v = 7. | v = 8. | v = 9. | v = 10. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ·5 | 1 in 497·5 | 1 in 290·5 | 1 in 171·2 | 1 in 95·6 | 1 in 44·3 | 1 in 7·5 | | | | | | | |
| 1·0 | „ 554·7 | „ 350·4 | „ 233·4 | „ 159·6 | „ 110·0 | „ 74·7 | 1 in 48·6 | 1 in 28·8 | 1 in 13·3 | | | | |
| 1·5 | „ 573·8 | „ 370·4 | „ 254·1 | „ 180·9 | „ 131·8 | „ 97·1 | „ 71·4 | „ 52·0 | „ 36·8 | 1 in 15·0 | | | |
| 2·0 | „ 583·3 | „ 380·4 | „ 264·5 | „ 191·6 | „ 142·8 | „ 108·3 | „ 82·8 | „ 63·7 | „ 48·6 | „ 27·0 | 1 in 12·4 | 1 in 2·1 | |
| 2·5 | „ 589·1 | „ 386·4 | „ 270·7 | „ 198·0 | „ 149·4 | „ 115·0 | „ 89·7 | „ 70·6 | „ 55·7 | „ 34·2 | „ 19·8 | „ 9·6 | 1 in 2·1 |
| 3·0 | „ 592·9 | „ 390·4 | „ 274·8 | „ 202·3 | „ 153·8 | „ 119·5 | „ 94·2 | „ 75·3 | „ 60·4 | „ 39·0 | „ 24·7 | „ 14·6 | „ 7·2 |
| 3·5 | „ 595·6 | „ 393·2 | „ 277·8 | „ 205·3 | „ 156·9 | „ 122·7 | „ 97·5 | „ 78·6 | „ 63·8 | „ 42·5 | „ 28·2 | „ 18·2 | „ 10·8 |
| 4·0 | „ 597·7 | „ 395·4 | „ 280·0 | „ 207·6 | „ 159·3 | „ 125·1 | „ 99·9 | „ 81·1 | „ 66·3 | „ 45·1 | „ 30·9 | „ 20·9 | „ 13·6 |
| 4·5 | „ 599·3 | „ 397·0 | „ 281·7 | „ 209·4 | „ 161·1 | „ 127·0 | „ 101·8 | „ 83·0 | „ 68·3 | „ 47·1 | „ 32·9 | „ 23·0 | „ 15·7 |
| 5·0 | „ 600·5 | „ 398·4 | „ 283·1 | „ 210·8 | „ 162·6 | „ 128·5 | „ 103·4 | „ 84·6 | „ 69·8 | „ 48·7 | „ 34·5 | „ 24·7 | „ 17·4 |
| 5·5 | „ 601·5 | „ 399·5 | „ 284·3 | „ 212·0 | „ 163·8 | „ 129·7 | „ 104·6 | „ 85·9 | „ 71·1 | „ 50·0 | „ 35·9 | „ 26·1 | „ 18·8 |
| 6·0 | „ 602·4 | „ 400·4 | „ 285·2 | „ 213·0 | „ 164·8 | „ 130·7 | „ 105·7 | „ 86·9 | „ 72·2 | „ 51·1 | „ 37·0 | „ 27·2 | „ 19·9 |
| 7·0 | „ 603·8 | „ 401·8 | „ 286·7 | „ 214·5 | „ 166·3 | „ 132·3 | „ 107·3 | „ 88·6 | „ 73·8 | „ 52·8 | „ 38·8 | „ 29·0 | „ 21·3 |
| 8·0 | „ 604·8 | „ 402·9 | „ 287·8 | „ 215·6 | „ 167·5 | „ 133·5 | „ 108·5 | „ 89·8 | „ 75·1 | „ 54·1 | „ 40·1 | „ 30·3 | „ 23·2 |
| 9·0 | „ 605·6 | „ 403·7 | „ 288·7 | „ 216·5 | „ 168·4 | „ 134·5 | „ 109·5 | „ 90·8 | „ 76·1 | „ 55·1 | „ 41·1 | „ 31·4 | „ 24·2 |
| 10·0 | „ 606·3 | „ 404·4 | „ 289·3 | „ 217·2 | „ 169·1 | „ 135·2 | „ 110·2 | „ 91·6 | „ 76·9 | „ 55·9 | „ 41·9 | „ 32·2 | „ 25·0 |
| 20·0 | „ 609·1 | „ 407·3 | „ 292·5 | „ 220·4 | „ 172·0 | „ 138·6 | „ 113·6 | „ 95·0 | „ 80·4 | „ 59·5 | „ 45·6 | „ 36·0 | „ 28·9 |
| 50·0 | „ 610·8 | „ 409·2 | „ 294·4 | „ 222·4 | „ 174·4 | „ 140·6 | „ 115·7 | „ 97·1 | „ 82·5 | „ 61·7 | „ 47·8 | „ 38·2 | „ 31·1 |
| Infinite | „ 612·0 | „ 410·4 | „ 295·6 | „ 223·6 | „ 175·7 | „ 141·9 | „ 117·0 | „ 98·5 | „ 84·0 | „ 63·2 | „ 49·3 | „ 39·7 | „ 32·7 |

h in the Table represents the total fall in a given length of sewer. The length of sewer taken into calculation is found by multiplying h by the rate of inclination of the sewer. Example: a sewer 1 foot diameter with a velocity of 3 feet per second, the total fall from head to outlet being 6 feet, the length of the sewer is 6×285·2=1711·2 feet. If the sewer is 6 feet diameter and the velocity required 3 feet, the total fall being 6 feet; the proper inclination = 6 × 285·2 = 1 in 1711, and the length of sewer taken into the calculation 6 × 1711 = 10,266 feet. The figures underlined are the points where the head h = the velocity, and corresponds with the inclination given in Table No. 7.

**TABLE No. 12.**—Showing the PROPER INCLINATION of EGG-SHAPED SEWERS, 1′ 0″ × 1′ 6″, when running full and working under various heads.

The proper inclination of any other sized egg-shaped sewer of the same relative proportions may be found by multiplying the inclination given in this Table by the transverse diameter of the sewer in feet and decimal parts of feet.

| h = | v = 2. | v = 2·5. | v = 3. | v = 3·5. | v = 4. | v = 4·5. | v = 5. | v = 5·5. | v = 6. |
|---|---|---|---|---|---|---|---|---|---|
| ·5 | 1 in 576·5 | 1 in 336·6 | 1 in 198·0 | 1 in 110·7 | 1 in 51·3 | 1 in 7·5 | | | |
| 1·0 | „ 642·8 | „ 406·0 | „ 270·0 | „ 184·9 | „ 127·4 | „ 86·5 | 1 in 56·3 | 1 in 33·3 | 1 in 15·4 |
| 1·5 | „ 664·9 | „ 429·2 | „ 294·0 | „ 209·6 | „ 152·7 | „ 112·5 | „ 82·7 | „ 60·2 | „ 42·6 |
| 2·0 | „ 675·9 | „ 440·8 | „ 306·5 | „ 222·0 | „ 165·4 | „ 125·4 | „ 95·9 | „ 73·8 | „ 56·3 |
| 2·5 | „ 682·6 | „ 447·7 | „ 313·6 | „ 229·4 | „ 173·0 | „ 133·3 | „ 103·9 | „ 81·8 | „ 64·5 |
| 3·0 | „ 687·0 | „ 452·3 | „ 318·4 | „ 234·4 | „ 178·2 | „ 138·4 | „ 109·1 | „ 87·2 | „ 69·9 |
| 3·5 | „ 690·0 | „ 455·6 | „ 321·9 | „ 237·9 | „ 181·8 | „ 142·1 | „ 112·9 | „ 91·0 | „ 73·9 |
| 4·0 | „ 692·6 | „ 458·1 | „ 324·4 | „ 240·5 | „ 184·5 | „ 144·9 | „ 115·7 | „ 93·9 | „ 76·8 |
| 4·5 | „ 694·4 | „ 460·0 | „ 326·4 | „ 242·6 | „ 186·6 | „ 147·1 | „ 117·9 | „ 96·1 | „ 79·1 |
| 5·0 | „ 695·8 | „ 461·6 | „ 328·0 | „ 244·2 | „ 188·4 | „ 148·9 | „ 119·8 | „ 98·0 | „ 80·8 |
| 5·5 | „ 697·0 | „ 462·9 | „ 329·4 | „ 245·6 | „ 189·8 | „ 150·2 | „ 121·2 | „ 99·4 | „ 82·3 |
| 6·0 | „ 698·0 | „ 463·9 | „ 330·4 | „ 246·8 | „ 190·9 | „ 151·4 | „ 122·4 | „ 100·6 | „ 83·6 |
| 7·0 | „ 699·7 | „ 465·6 | „ 332·2 | „ 248·5 | „ 192·7 | „ 153·3 | „ 124·3 | „ 102·6 | „ 85·5 |
| 8·0 | „ 700·8 | „ 466·8 | „ 333·5 | „ 249·8 | „ 194·0 | „ 154·69 | „ 125·7 | „ 104·0 | „ 87·0 |
| 9·0 | „ 701·8 | „ 467·8 | „ 334·5 | „ 250·8 | „ 195·0 | „ 155·8 | „ 126·8 | „ 105·2 | „ 88·1 |
| 10·0 | „ 702·6 | „ 468·6 | „ 335·2 | „ 251·6 | „ 195·9 | „ 156·6 | „ 127·6 | „ 106·1 | „ 89·1 |
| 20·0 | „ 705·8 | „ 472·0 | „ 338·9 | „ 255·3 | „ 199·3 | „ 160·6 | „ 131·6 | „ 110·0 | „ 93·1 |
| 50·0 | „ 707·8 | „ 474·1 | „ 341·0 | „ 257·7 | „ 202·0 | „ 162·9 | „ 134·0 | „ 112·5 | „ 95·7 |
| Infinite. | „ 709·2 | „ 475·5 | „ 342·5 | „ 259·1 | „ 203·6 | „ 164·4 | „ 135·5 | „ 114·1 | „ 97·3 |

**Example**:—The proper inclination for a sewer 3′ 0″ × 4′ 6″, the total fall in the length taken into consideration = 9 feet, the velocity required being 2 feet per second, then 3 feet × 701·8 = 2105·4 = 1 in 2105.

TABLE No. 13.—Showing the PROPER INCLINATION of EGG-SHAPED SEWERS, 1′ 0″ × 1′ 6″, when running two-thirds full and working under various heads.

The proper inclination of any other sized egg-shaped sewer of the same relative proportions may be found by multiplying the inclination given in this Table by the transverse diameter of the sewer in feet and decimal parts of feet.

| $h$ = | $v$ = 2. | $v$ = 2·5. | $v$ = 3. | $v$ = 3·5. | $v$ = 4. | $v$ = 4·5. | $v$ = 5. | $v$ = 5·5. | $v$ = 6. |
|---|---|---|---|---|---|---|---|---|---|
| ·5 | 1 in 628·2 | 1 in 366·8 | 1 in 216·2 | 1 in 120·7 | 1 in 55·9 | 1 in 9·4 | | | |
| 1·0 | „ 700·4 | „ 442·4 | „ 294·7 | „ 201·5 | „ 138·9 | „ 94·3 | 1 in 61·3 | 1 in 36·3 | 1 in 16·7 |
| 1·5 | „ 724·6 | „ 467·7 | „ 320·8 | „ 228·4 | „ 166·4 | „ 122·6 | „ 90·1 | „ 65·6 | „ 46·4 |
| 2·0 | „ 736·6 | „ 480·0 | „ 334·4 | „ 241·9 | „ 180·3 | „ 136·7 | „ 104·5 | „ 80·3 | „ 61·3 |
| 2·5 | „ 743·9 | „ 487·9 | „ 341·8 | „ 250·0 | „ 188·6 | „ 145·3 | „ 113·2 | „ 89·1 | „ 70·3 |
| 3·0 | „ 748·7 | „ 492·9 | „ 347·0 | „ 255·4 | „ 194·2 | „ 150·9 | „ 118·9 | „ 95·0 | „ 76·2 |
| 3·5 | „ 752·0 | „ 496·5 | „ 350·8 | „ 259·2 | „ 198·1 | „ 154·9 | „ 123·1 | „ 99·2 | „ 80·5 |
| 4·0 | „ 754·7 | „ 499·3 | „ 353·5 | „ 262·1 | „ 201·1 | „ 157·9 | „ 126·1 | „ 102·4 | „ 83·7 |
| 4·5 | „ 757·5 | „ 501·3 | „ 355·7 | „ 264·4 | „ 203·4 | „ 160·3 | „ 128·5 | „ 104·8 | „ 86·2 |
| 5·0 | „ 758·3 | „ 503 0 | „ 357·5 | „ 266·2 | „ 205·3 | „ 162·2 | „ 130·5 | „ 106·8 | „ 88·1 |
| 5·5 | „ 759·5 | „ 504·4 | „ 359·0 | „ 267·7 | „ 206·8 | „ 163·7 | „ 132·0 | „ 108·3 | „ 89·7 |
| 6·0 | „ 760·7 | „ 505·6 | „ 360·1 | „ 268·9 | „ 208·1 | „ 165·0 | „ 133·4 | „ 109·7 | „ 91·1 |
| 7·0 | „ 762·4 | „ 507·3 | „ 362·0 | „ 270·8 | „ 210·0 | „ 167·0 | „ 135·4 | „ 111·8 | „ 93·1 |
| 8·0 | „ 763·7 | „ 508·7 | „ 363·0 | „ 272·2 | „ 211·5 | „ 168·5 | „ 137·0 | „ 113·3 | „ 94·8 |
| 9·0 | „ 764·7 | „ 509·7 | „ 364·5 | „ 273·4 | „ 212·6 | „ 169·8 | „ 138·2 | „ 114·6 | „ 96·0 |
| 10·0 | „ 765·6 | „ 510·6 | „ 365·3 | „ 274·2 | „ 213·5 | „ 170·7 | „ 139·1 | „ 115·6 | „ 97·1 |
| 20·0 | „ 769·0 | „ 514·4 | „ 369·3 | „ 278·3 | „ 217·2 | „ 175·0 | „ 143·4 | „ 119·9 | „ 101·5 |
| 50·0 | „ 771·3 | „ 516·7 | „ 371·7 | „ 280·8 | „ 220·2 | „ 177·5 | „ 146·1 | „ 122·6 | „ 104·1 |
| Infinite. | „ 772·8 | „ 518·2 | „ 373·2 | „ 282·2 | „ 221·8 | „ 179·1 | „ 147·7 | „ 124·3 | „ 106·0 |

TABLE No. 14.—Showing the PROPER INCLINATION of EGG-SHAPED SEWERS, 1′ 0″ × 1′ 6″, when running one-third full and working under various heads.

The proper inclination of any other sized egg-shaped sewer of the same relative proportions may be found by multiplying the inclination given in this Table by the transverse diameter of the sewer in feet and decimal parts of feet.

| A = | v = 2. | v = 2·5. | v = 3. | v = 3·5. | v = 4. | v = 4·5. | v = 5. | v = 5·5. | v = 6. |
|---|---|---|---|---|---|---|---|---|---|
| 0·5 | 1 in 411·1 | 1 in 240·0 | 1 in 141·4 | 1 in 79·0 | 1 in 36·6 | 1 in 6·1 | | | |
| 1·0 | „ 458·4 | „ 289·5 | „ 192·8 | „ 131·8 | „ 90·9 | „ 61·7 | 1 in 40·1 | 1 in 23·8 | 1 in 10·9 |
| 1·5 | „ 474·1 | „ 306·0 | „ 209·9 | „ 149·4 | „ 108·9 | „ 80·2 | „ 59·0 | „ 42·9 | „ 30·4 |
| 2·0 | „ 482·9 | „ 314·3 | „ 218·5 | „ 158·3 | „ 118·0 | „ 89·5 | „ 68·4 | „ 52·6 | „ 40·1 |
| 2·5 | „ 486·8 | „ 319·3 | „ 223·7 | „ 163·6 | „ 123·4 | „ 95·1 | „ 74·1 | „ 58·3 | „ 46·0 |
| 3·0 | „ 489·9 | „ 322·6 | „ 227·0 | „ 167·1 | „ 127·1 | „ 98·7 | „ 77·8 | „ 62·2 | „ 49·9 |
| 3·5 | „ 492·2 | „ 324·9 | „ 229·5 | „ 169·6 | „ 129·6 | „ 101·3 | „ 80·5 | „ 64·9 | „ 52·7 |
| 4·0 | „ 493·9 | „ 326·7 | „ 231·3 | „ 171·5 | „ 131·6 | „ 103·3 | „ 82·5 | „ 67·0 | „ 54·7 |
| 4·5 | „ 495·7 | „ 328·0 | „ 232·7 | „ 173·0 | „ 133·1 | „ 104·9 | „ 84·1 | „ 68·5 | „ 56·4 |
| 5·0 | „ 496·2 | „ 329·2 | „ 233·9 | „ 174·2 | „ 134·3 | „ 106·2 | „ 85·4 | „ 69·9 | „ 57·6 |
| 5·5 | „ 497·0 | „ 330·1 | „ 234·9 | „ 175·1 | „ 135·3 | „ 107·1 | „ 86·4 | „ 70·9 | „ 58·7 |
| 6·0 | „ 497·8 | „ 330·8 | „ 235·6 | „ 176·0 | „ 136·1 | „ 108·0 | „ 87·3 | „ 71·8 | „ 59·6 |
| 7·0 | „ 498·9 | „ 332·0 | „ 236·9 | „ 177·2 | „ 137·4 | „ 109·3 | „ 88·6 | „ 73·2 | „ 60·9 |
| 8·0 | „ 499·8 | „ 332·9 | „ 237·8 | „ 178·1 | „ 138·4 | „ 110·3 | „ 89·6 | „ 74·2 | „ 62·0 |
| 9·0 | „ 500·4 | „ 333·6 | „ 238·5 | „ 178·9 | „ 139·1 | „ 111·1 | „ 90·4 | „ 75·0 | „ 62·8 |
| 10·0 | „ 501·0 | „ 334·1 | „ 239·0 | „ 179·4 | „ 139·7 | „ 111·7 | „ 91·0 | „ 75·6 | „ 63·5 |
| 20·0 | „ 503·3 | „ 336·6 | „ 241·7 | „ 182·1 | „ 142·1 | „ 114·5 | „ 93·8 | „ 78·5 | „ 66·4 |
| 50·0 | „ 504·7 | „ 338·1 | „ 243·2 | „ 183·7 | „ 144·1 | „ 116·1 | „ 95·6 | „ 80·2 | „ 68·1 |
| Infinite. | „ 505·7 | „ 339·1 | „ 244·2 | „ 184·7 | „ 145·1 | „ 117·2 | „ 96·6 | „ 82·4 | „ 69·4 |

TABLE No. 15.—VELOCITIES in feet per minute in CIRCULAR SEWER

| Rate of Inclination. | Size, d=4". | Size, d=6". | Size, d=8". | Size, d=9". | Size, d=10". | Size, d=12". | Size, d=15". | Size, d=18". | Size, d=20". | Size, d=22". | Size, d=24". | Size, d=30". | Size, d=36". | Size, d=40". |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 in 50 | 246 | 307 | 354 | 375 | 394 | 432 | 481 | 525 | | | | | | |
| „ 60 | 226 | 279 | 323 | 343 | 361 | 395 | 440 | 481 | | | | | | |
| „ 70 | 209 | 251 | 298 | 317 | 334 | 366 | 408 | 446 | | | | | | |
| „ 80 | 194 | 239 | 278 | 296 | 312 | 342 | 382 | 418 | | | | | | |
| „ 90 | 182 | 225 | 262 | 279 | 294 | 322 | 360 | 394 | | | | | | |
| „ 100 | 172 | 213 | 248 | 264 | 279 | 306 | 342 | 374 | 394 | 413 | 432 | | | |
| „ 110 | 163 | 202 | 236 | 251 | 265 | 291 | 326 | 357 | 376 | 395 | 413 | | | |
| „ 120 | 155 | 193 | 225 | 240 | 253 | 278 | 312 | 342 | 360 | 378 | 395 | | | |
| „ 130 | 149 | 186 | 216 | 230 | 243 | 267 | 299 | 328 | 346 | 363 | 379 | | | |
| „ 140 | 143 | 178 | 208 | 221 | 233 | 257 | 288 | 316 | 334 | 350 | 365 | | | |
| „ 150 | 138 | 172 | 201 | 213 | 225 | 248 | 278 | 306 | 322 | 338 | 353 | | | |
| „ 160 | 133 | 166 | 194 | 206 | 218 | 240 | 269 | 296 | 312 | 327 | 342 | | | |
| „ 170 | 129 | 160 | 188 | 199 | 211 | 232 | 261 | 287 | 303 | 317 | 332 | | | |
| „ 180 | 125 | 155 | 182 | 193 | 205 | 225 | 253 | 278 | 294 | 308 | 322 | | | |
| „ 190 | 121 | 151 | 177 | 188 | 199 | 219 | 246 | 270 | 286 | 300 | 313 | | | |
| „ 200 | 118 | 147 | 172 | 183 | 194 | 213 | 239 | 263 | 278 | 292 | 305 | 342 | 375 | 395 |
| „ 250 | .. | 131 | 153 | 163 | 172 | 189 | 213 | 234 | 247 | 260 | 272 | 305 | 335 | 353 |
| „ 300 | .. | 118 | 138 | 147 | 156 | 172 | 193 | 213 | 225 | 237 | 248 | 278 | 305 | 322 |
| „ 350 | .. | .. | 127 | 135 | 143 | 158 | 178 | 196 | 207 | 218 | 228 | 256 | 282 | 298 |
| „ 400 | .. | .. | 118 | 126 | 133 | 147 | 166 | 183 | 193 | 203 | 213 | 239 | 263 | 278 |
| „ 450 | .. | .. | .. | 118 | 125 | 138 | 156 | 172 | 182 | 191 | 200 | 225 | 247 | 261 |
| „ 500 | .. | .. | .. | .. | 118 | 130 | 147 | 162 | 172 | 181 | 189 | 213 | 234 | 247 |
| „ 550 | .. | .. | .. | .. | .. | 124 | 140 | 154 | 163 | 172 | 180 | 203 | 223 | 235 |
| „ 600 | .. | .. | .. | .. | .. | 118 | 134 | 147 | 156 | 164 | 172 | 194 | 213 | 225 |
| „ 650 | .. | .. | .. | .. | .. | .. | 128 | 141 | 149 | 157 | 165 | 186 | 204 | 216 |
| „ 700 | .. | .. | .. | .. | .. | .. | 123 | 135 | 143 | 151 | 158 | 179 | 196 | 208 |
| „ 750 | .. | .. | .. | .. | .. | .. | 118 | 130 | 138 | 145 | 152 | 172 | 189 | 201 |
| „ 800 | .. | .. | .. | .. | .. | .. | .. | 126 | 133 | 140 | 147 | 166 | 183 | 194 |
| „ 850 | .. | .. | .. | .. | .. | .. | .. | 122 | 129 | 136 | 142 | 161 | 177 | 188 |
| „ 900 | .. | .. | .. | .. | .. | .. | .. | 118 | 125 | 132 | 138 | 156 | 172 | 182 |
| „ 950 | .. | .. | .. | .. | .. | .. | .. | .. | 121 | 128 | 134 | 151 | 167 | 177 |
| „ 1000 | .. | .. | .. | .. | .. | .. | .. | .. | 118 | 124 | 130 | 147 | 162 | 172 |
| „ 1100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 118 | 124 | 140 | 154 | 163 |
| „ 1200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 118 | 133 | 147 | 156 |
| „ 1300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 127 | 141 | 149 |
| „ 1400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 122 | 135 | 143 |
| „ 1500 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 118 | 130 | 138 |
| „ 1600 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 126 | 133 |
| „ 1700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 122 | 129 |
| „ 1800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 118 | 125 |
| „ 1900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 121 |
| „ 2000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 118 |
| „ 2100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2500 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2600 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3500 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3600 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4500 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4600 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 5000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 5100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 5400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 5700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 6000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |

*In this Table the length of sewer taken into consideration = the rate of inclination × by the velocity in feet per second.*
*Example.—A sewer 12" having an inclination of 1 in 160, the velocity in feet per minute as given by this Table = 240*
*the velocity per second = 4 feet, and the length of sewer to which this Table applies = 4 × 160 = 640 feet.*

## ...n running full or half full, at VARIOUS RATES of INCLINATION.

| Size, d=... | Size, d=48". | Size, d=54". | Size, d=60". | Size, d=66". | Size, d=72". | Size, d=78". | Size, d=84". | Size, d=90". | Size, d=96". | Size, d=102". | Size, d=108". | Size, d=114". | Size, d=120". | Rate of Inclination |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | 1 in |
| | | | | | | | | | | | | | | " |
| | | | | | | | | | | | | | | " |
| | | | | | | | | | | | | | | " |
| | | | | | | | | | | | | | | " |
| | | | | | | | | | | | | | | " |
| | | | | | | | | | | | | | | " |
| | | | | | | | | | | | | | | " |
| | | | | | | | | | | | | | | " |
| | | | | | | | | | | | | | | " |
| | | | | | | | | | | | | | | " |
| | | | | | | | | | | | | | | " |
| | | | | | | | | | | | | | | " |
| | | | | | | | | | | | | | | " |
| 120 | 431 | 457 | 481 | 503 | 524 | | | | | | | | | " |
| 115 | 397 | 411 | 433 | 453 | 472 | | | | | | | | | " |
| 110 | 363 | 375 | 395 | 414 | 431 | | | | | | | | | " |
| 105 | 327 | 347 | 366 | 384 | 400 | | | | | | | | | " |
| 100 | 306 | 325 | 342 | 359 | 375 | | | | | | | | | " |
| 95 | 289 | 307 | 323 | 339 | 354 | | | | | | | | | " |
| 90 | 273 | 290 | 306 | 321 | 335 | 349 | 362 | 375 | 387 | 399 | 410 | 421 | 432 | " |
| 85 | 260 | 276 | 291 | 305 | 319 | 332 | 344 | 356 | 368 | 379 | 390 | 401 | 412 | " |
| 80 | 248 | 263 | 278 | 292 | 305 | 318 | 330 | 342 | 353 | 364 | 375 | 385 | 395 | " |
| 75 | 238 | 253 | 267 | 280 | 293 | 305 | 317 | 329 | 340 | 350 | 360 | 370 | 380 | " |
| 72 | 229 | 243 | 257 | 270 | 282 | 294 | 305 | 316 | 327 | 337 | 347 | 357 | 366 | " |
| 70 | 221 | 235 | 248 | 260 | 272 | 284 | 295 | 305 | 315 | 325 | 335 | 345 | 354 | " |
| 68 | 213 | 226 | 239 | 251 | 263 | 274 | 285 | 295 | 305 | 315 | 324 | 333 | 342 | " |
| 66 | 206 | 219 | 231 | 243 | 255 | 266 | 276 | 285 | 296 | 306 | 314 | 323 | 331 | " |
| 64 | 200 | 213 | 225 | 236 | 247 | 258 | 268 | 278 | 287 | 296 | 305 | 314 | 322 | " |
| 62 | 195 | 207 | 219 | 230 | 240 | 251 | 261 | 270 | 279 | 288 | 297 | 305 | 313 | " |
| 60 | 190 | 202 | 213 | 224 | 234 | 244 | 254 | 263 | 272 | 281 | 289 | 297 | 305 | " 1 |
| 58 | 181 | 192 | 203 | 213 | 223 | 232 | 241 | 250 | 259 | 268 | 276 | 283 | 290 | " 1 |
| 56 | 172 | 183 | 193 | 203 | 213 | 222 | 231 | 240 | 248 | 256 | 264 | 271 | 278 | " 1 |
| 54 | 165 | 175 | 185 | 195 | 204 | 213 | 222 | 230 | 238 | 245 | 253 | 260 | 267 | " 1 |
| 52 | 158 | 168 | 178 | 187 | 196 | 205 | 213 | 221 | 229 | 236 | 243 | 250 | 257 | " 1 |
| 50 | 152 | 162 | 172 | 181 | 189 | 197 | 205 | 213 | 221 | 228 | 235 | 241 | 248 | " 1 |
| 48 | 147 | 157 | 166 | 175 | 183 | 191 | 199 | 206 | 213 | 220 | 227 | 233 | 239 | " 1 |
| 46 | 142 | 152 | 161 | 169 | 177 | 185 | 192 | 200 | 206 | 213 | 220 | 226 | 232 | " 1 |
| 44 | 138 | 147 | 156 | 164 | 172 | 180 | 187 | 194 | 200 | 207 | 213 | 219 | 225 | " 1 |
| 42 | 134 | 143 | 151 | 159 | 167 | 174 | 181 | 188 | 194 | 201 | 207 | 213 | 219 | " 1 |
| 40 | 130 | 139 | 147 | 155 | 162 | 169 | 176 | 183 | 189 | 196 | 201 | 207 | 213 | " 2 |
| 38 | 127 | 135 | 143 | 151 | 158 | 165 | 172 | 178 | 184 | 190 | 196 | 202 | 208 | " 2 |
| 36 | 124 | 132 | 140 | 147 | 154 | 161 | 168 | 174 | 180 | 186 | 192 | 198 | 203 | " 2 |
| 34 | 121 | 129 | 136 | 143 | 150 | 157 | 164 | 170 | 176 | 182 | 187 | 193 | 198 | " 2 |
| 32 | 118 | 126 | 133 | 140 | 147 | 154 | 160 | 166 | 172 | 178 | 183 | 188 | 193 | " 2 |
| 30 | .. | 123 | 130 | 137 | 144 | 150 | 156 | 162 | 168 | 174 | 179 | 184 | 189 | " 2 |
| 28 | .. | 120 | 128 | 135 | 141 | 147 | 153 | 159 | 165 | 170 | 175 | 180 | 185 | " 2 |
| 26 | .. | 118 | 125 | 132 | 138 | 144 | 150 | 156 | 161 | 166 | 171 | 176 | 181 | " 2 |
| 24 | .. | .. | 123 | 129 | 135 | 141 | 147 | 153 | 158 | 163 | 168 | 173 | 178 | " 2 |
| 22 | .. | .. | 120 | 126 | 132 | 138 | 144 | 150 | 155 | 160 | 165 | 170 | 175 | " 2 |
| 20 | .. | .. | 118 | 124 | 130 | 136 | 142 | 148 | 153 | 158 | 163 | 168 | 172 | " 3 |
| 19 | .. | .. | .. | 122 | 128 | 134 | 139 | 145 | 150 | 155 | 160 | 165 | 169 | " 3 |
| 18 | .. | .. | .. | 120 | 126 | 132 | 137 | 142 | 147 | 152 | 157 | 162 | 166 | " 3 |
| 17 | .. | .. | .. | 118 | 124 | 130 | 135 | 140 | 145 | 150 | 155 | 159 | 163 | " 3 |
| 16 | .. | .. | .. | .. | 122 | 128 | 133 | 138 | 143 | 148 | 153 | 157 | 161 | " 3 |
| 15 | .. | .. | .. | .. | 120 | 126 | 131 | 136 | 141 | 146 | 150 | 154 | 158 | " 3 |
| 14 | .. | .. | .. | .. | 118 | 124 | 129 | 134 | 139 | 144 | 147 | 152 | 156 | " 3 |
| 13 | .. | .. | .. | .. | .. | 122 | 127 | 132 | 137 | 141 | 145 | 149 | 153 | " 3 |
| 12 | .. | .. | .. | .. | .. | 120 | 125 | 130 | 135 | 139 | 143 | 147 | 151 | " 3 |
| 11 | .. | .. | .. | .. | .. | 118 | 123 | 129 | 133 | 137 | 141 | 145 | 149 | " 3 |
| 10 | .. | .. | .. | .. | .. | .. | 121 | 126 | 131 | 135 | 139 | 143 | 147 | " 4 |
| 9 | .. | .. | .. | .. | .. | .. | 119 | 124 | 129 | 133 | 137 | 141 | 145 | " 4 |
| 8 | .. | .. | .. | .. | .. | .. | 118 | 123 | 127 | 131 | 135 | 139 | 143 | " 4 |
| 7 | .. | .. | .. | .. | .. | .. | .. | 121 | 125 | 129 | 133 | 137 | 141 | " 4 |
| 6 | .. | .. | .. | .. | .. | .. | .. | 120 | 124 | 128 | 132 | 136 | 140 | " 4 |
| 5 | .. | .. | .. | .. | .. | .. | .. | 118 | 122 | 126 | 130 | 134 | 138 | " 4 |
| 4 | .. | .. | .. | .. | .. | .. | .. | .. | 121 | 125 | 129 | 133 | 136 | " 4 |
| 3 | .. | .. | .. | .. | .. | .. | .. | .. | 119 | 123 | 127 | 131 | 134 | " 4 |
| 2 | .. | .. | .. | .. | .. | .. | .. | .. | 118 | 122 | 126 | 130 | 133 | " 4 |
| 1 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 124 | 128 | 131 | " 4 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 119 | 123 | 127 | 130 | " 5 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 118 | 122 | 126 | 129 | " 5 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 118 | 122 | 125 | " 5 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 118 | 121 | " 5 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 118 | " 6 |

For all practical purposes *the velocities given in this* Table may be taken as correct; in cases in which great accuracy *...ained the proper inclination will be found from* Table No. 11.

TABLE No. 16.—TABLE of VELOCITIES in feet per minute in Eq

| Inclination. | Size, 1′ 0″ × 1′ 6″. | Size, 1′ 2″ × 1′ 9″. | Size, 1′ 4″ × 2′ 0″. | Size, 1′ 6″ × 2′ 3″. | Size, 1′ 8″ × 2′ 6″. | Size, 1′ 10″ × 2′ 9″. | Size, 2′ 0″ × 3′ 0″. | Size, 2′ 2″ × 3′ 3″. | Size, 2′ 4″ × 3′ 6″. | Size, 2′ 6″ × 3′ 9″. | Size, 2′ 8″ × 4′ 0″. | Size, 2′ 10″ × 4′ 3″. | Size, 3′ 0″ × 4′ 6″. | Size, 3′ 2″ × 4′ 9″. | Size 3′ 4 × 5′ 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 in 100 | 329 | 356 | 381 | 404 | 425 | 444 | 463 | | | | | | | | |
| „ 110 | 314 | 339 | 363 | 385 | 405 | 424 | 442 | | | | | | | | |
| „ 120 | 300 | 324 | 347 | 368 | 388 | 407 | 424 | | | | | | | | |
| „ 130 | 288 | 312 | 334 | 354 | 373 | 391 | 408 | | | | | | | | |
| „ 140 | 277 | 300 | 321 | 341 | 359 | 377 | 393 | | | | | | | | |
| „ 150 | 267 | 289 | 310 | 329 | 347 | 364 | 380 | | | | | | | | |
| „ 160 | 258 | 280 | 300 | 319 | 336 | 353 | 368 | | | | | | | | |
| „ 170 | 250 | 271 | 291 | 309 | 326 | 342 | 357 | | | | | | | | |
| „ 180 | 243 | 263 | 282 | 300 | 317 | 332 | 347 | | | | | | | | |
| „ 190 | 236 | 256 | 275 | 292 | 308 | 323 | 338 | | | | | | | | |
| „ 200 | 230 | 249 | 267 | 284 | 300 | 315 | 329 | 343 | 356 | 368 | 380 | 392 | 403 | 414 | 425 |
| „ 250 | 205 | 222 | 238 | 253 | 267 | 281 | 294 | 306 | 318 | 329 | 340 | 351 | 361 | 371 | 381 |
| „ 300 | 186 | 202 | 216 | 230 | 243 | 256 | 268 | 279 | 290 | 300 | 310 | 320 | 330 | 339 | 348 |
| „ 350 | 171 | 186 | 199 | 212 | 224 | 236 | 247 | 258 | 268 | 277 | 286 | 295 | 304 | 313 | 321 |
| „ 400 | 159 | 173 | 186 | 198 | 209 | 220 | 230 | 240 | 250 | 259 | 268 | 276 | 284 | 292 | 300 |
| „ 450 | 149 | 162 | 174 | 186 | 197 | 207 | 217 | 226 | 235 | 244 | 252 | 260 | 268 | 276 | 283 |
| „ 500 | 141 | 153 | 165 | 176 | 186 | 196 | 205 | 214 | 222 | 230 | 238 | 246 | 253 | 260 | 267 |
| „ 550 | 134 | 146 | 157 | 167 | 177 | 186 | 195 | 203 | 211 | 219 | 226 | 233 | 240 | 247 | 254 |
| „ 600 | 128 | 139 | 149 | 159 | 169 | 178 | 186 | 194 | 202 | 209 | 216 | 223 | 230 | 237 | 243 |
| „ 650 | 123 | 133 | 143 | 152 | 161 | 170 | 178 | 186 | 193 | 200 | 207 | 214 | 221 | 227 | 233 |
| „ 700 | 118 | 128 | 137 | 146 | 155 | 163 | 171 | 179 | 186 | 193 | 200 | 206 | 212 | 218 | 224 |
| „ 750 | .. | 123 | 132 | 141 | 149 | 157 | 165 | 172 | 179 | 186 | 193 | 199 | 205 | 211 | 216 |
| „ 800 | .. | 119 | 128 | 136 | 144 | 152 | 159 | 166 | 173 | 180 | 186 | 192 | 198 | 204 | 209 |
| „ 850 | .. | .. | 124 | 132 | 140 | 147 | 154 | 161 | 168 | 174 | 180 | 186 | 192 | 197 | 202 |
| „ 900 | .. | .. | 120 | 128 | 136 | 143 | 150 | 156 | 162 | 168 | 174 | 180 | 186 | 191 | 196 |
| „ 950 | .. | .. | .. | 124 | 132 | 139 | 145 | 151 | 157 | 163 | 169 | 175 | 180 | 185 | 190 |
| „ 1000 | .. | .. | .. | 121 | 128 | 135 | 141 | 147 | 153 | 159 | 165 | 170 | 175 | 180 | 185 |
| „ 1100 | .. | .. | .. | .. | 121 | 128 | 134 | 140 | 146 | 152 | 157 | 162 | 167 | 172 | 177 |
| „ 1200 | .. | .. | .. | .. | .. | 122 | 128 | 134 | 140 | 145 | 150 | 154 | 159 | 164 | 168 |
| „ 1300 | .. | .. | .. | .. | .. | .. | 122 | 128 | 134 | 139 | 143 | 148 | 152 | 157 | 161 |
| „ 1400 | .. | .. | .. | .. | .. | .. | .. | 123 | 128 | 133 | 137 | 142 | 146 | 151 | 155 |
| „ 1500 | .. | .. | .. | .. | .. | .. | .. | 118 | 123 | 128 | 133 | 137 | 141 | 145 | 149 |
| „ 1600 | .. | .. | .. | .. | .. | .. | .. | .. | 118 | 123 | 128 | 132 | 136 | 140 | 144 |
| „ 1700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 119 | 124 | 128 | 132 | 136 | 140 |
| „ 1800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 124 | 128 | 132 | 136 |
| „ 1900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 124 | 128 | 132 |
| „ 2000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 121 | 125 | 128 |
| „ 2100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 122 | 125 |
| „ 2200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 119 | 122 |
| „ 2300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 119 |
| „ 2400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2500 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2600 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3500 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3600 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |

APED SEWERS, when running full at VARIOUS RATES of INCLINATION.

| s, F' | Size, 3' 8" × 5' 6". | Size, 3' 10" × 5' 9". | Size, 4' 0" × 6' 0". | Size, 4' 2" × 6' 3". | Size, 4' 4" × 6' 6". | Size, 4' 6" × 6' 9". | Size, 4' 8" × 7' 0". | Size, 4' 10" × 7' 3". | Size, 5' 0" × 7' 6". | Size, 5' 2" × 7' 9". | Size, 5' 4" × 8' 0". | Size, 5' 6" × 8' 3". | Size, 5' 8" × 8' 6". | Size, 5' 10" × 8' 9". | Size, 6' 0" × 9' 0". | Inclination. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | 1 in 100 |
| | | | | | | | | | | | | | | | | „ 110 |
| | | | | | | | | | | | | | | | | „ 120 |
| | | | | | | | | | | | | | | | | „ 130 |
| | | | | | | | | | | | | | | | | „ 140 |
| | | | | | | | | | | | | | | | | „ 150 |
| | | | | | | | | | | | | | | | | „ 160 |
| | | | | | | | | | | | | | | | | „ 170 |
| | | | | | | | | | | | | | | | | „ 180 |
| | | | | | | | | | | | | | | | | „ 190 |
| | 445 | 454 | 463 | 472 | 481 | 490 | 499 | 508 | 516 | 524 | 532 | 540 | 548 | 556 | 563 | „ 200 |
| | 399 | 408 | 416 | 424 | 432 | 440 | 448 | 456 | 464 | 471 | 479 | 486 | 493 | 500 | 507 | „ 250 |
| | 364 | 372 | 380 | 388 | 395 | 403 | 410 | 417 | 424 | 431 | 438 | 445 | 451 | 457 | 463 | „ 300 |
| | 337 | 344 | 352 | 359 | 366 | 373 | 380 | 387 | 393 | 400 | 406 | 412 | 418 | 424 | 430 | „ 350 |
| | 315 | 322 | 329 | 336 | 343 | 350 | 356 | 362 | 368 | 374 | 380 | 386 | 392 | 398 | 403 | „ 400 |
| | 297 | 304 | 311 | 317 | 323 | 329 | 335 | 341 | 347 | 353 | 358 | 364 | 369 | 375 | 380 | „ 450 |
| | 281 | 288 | 294 | 300 | 306 | 312 | 318 | 324 | 329 | 335 | 340 | 346 | 351 | 356 | 361 | „ 500 |
| | 267 | 274 | 280 | 286 | 292 | 298 | 303 | 309 | 314 | 319 | 324 | 329 | 334 | 339 | 344 | „ 550 |
| | 255 | 261 | 267 | 273 | 279 | 284 | 289 | 295 | 300 | 305 | 310 | 315 | 320 | 325 | 329 | „ 600 |
| | 245 | 251 | 257 | 262 | 267 | 272 | 277 | 282 | 287 | 292 | 297 | 302 | 307 | 312 | 316 | „ 650 |
| | 236 | 242 | 247 | 252 | 257 | 262 | 267 | 272 | 277 | 282 | 287 | 291 | 296 | 300 | 304 | „ 700 |
| | 228 | 233 | 238 | 243 | 248 | 253 | 258 | 263 | 268 | 272 | 277 | 281 | 286 | 290 | 294 | „ 750 |
| | 220 | 225 | 230 | 235 | 240 | 245 | 250 | 255 | 259 | 263 | 268 | 272 | 276 | 280 | 284 | „ 800 |
| | 213 | 218 | 223 | 228 | 233 | 237 | 242 | 247 | 251 | 255 | 259 | 263 | 267 | 271 | 275 | „ 850 |
| | 206 | 211 | 216 | 221 | 226 | 230 | 235 | 239 | 243 | 247 | 251 | 255 | 259 | 263 | 267 | „ 900 |
| | 200 | 205 | 210 | 215 | 219 | 223 | 228 | 232 | 236 | 240 | 244 | 248 | 252 | 256 | 260 | „ 950 |
| | 195 | 200 | 205 | 209 | 213 | 217 | 222 | 226 | 230 | 234 | 238 | 242 | 246 | 250 | 253 | „ 1000 |
| | 186 | 191 | 195 | 199 | 203 | 207 | 211 | 215 | 219 | 223 | 227 | 230 | 234 | 238 | 241 | „ 1100 |
| | 178 | 182 | 186 | 190 | 194 | 198 | 202 | 206 | 209 | 213 | 216 | 219 | 223 | 227 | 230 | „ 1200 |
| | 170 | 174 | 178 | 182 | 186 | 190 | 193 | 197 | 200 | 204 | 207 | 210 | 214 | 217 | 220 | „ 1300 |
| | 163 | 167 | 171 | 175 | 178 | 182 | 185 | 189 | 192 | 196 | 199 | 202 | 206 | 209 | 212 | „ 1400 |
| | 157 | 161 | 165 | 169 | 172 | 176 | 179 | 183 | 186 | 189 | 192 | 195 | 198 | 201 | 204 | „ 1500 |
| | 152 | 156 | 159 | 163 | 166 | 170 | 173 | 177 | 180 | 183 | 186 | 189 | 192 | 195 | 198 | „ 1600 |
| | 147 | 151 | 154 | 158 | 161 | 164 | 167 | 171 | 174 | 177 | 180 | 183 | 186 | 189 | 192 | „ 1700 |
| | 142 | 146 | 149 | 153 | 156 | 159 | 162 | 166 | 169 | 172 | 175 | 177 | 180 | 183 | 186 | „ 1800 |
| | 138 | 142 | 145 | 148 | 151 | 154 | 157 | 161 | 164 | 167 | 170 | 172 | 175 | 178 | 181 | „ 1900 |
| | 134 | 138 | 141 | 144 | 147 | 150 | 153 | 156 | 159 | 162 | 165 | 167 | 170 | 173 | 176 | „ 2000 |
| | 131 | 134 | 137 | 140 | 143 | 146 | 149 | 152 | 155 | 158 | 161 | 163 | 166 | 169 | 171 | „ 2100 |
| | 128 | 131 | 134 | 137 | 140 | 143 | 146 | 149 | 151 | 154 | 157 | 159 | 162 | 165 | 167 | „ 2200 |
| | 125 | 128 | 131 | 134 | 137 | 140 | 142 | 145 | 148 | 150 | 153 | 155 | 158 | 161 | 163 | „ 2300 |
| | 122 | 125 | 128 | 131 | 134 | 137 | 139 | 142 | 145 | 147 | 150 | 152 | 155 | 157 | 159 | „ 2400 |
| | 119 | 122 | 125 | 128 | 131 | 134 | 136 | 139 | 141 | 144 | 147 | 149 | 151 | 154 | 156 | „ 2500 |
| | .. | 120 | 122 | 125 | 128 | 131 | 133 | 136 | 138 | 141 | 143 | 146 | 148 | 151 | 153 | „ 2600 |
| | .. | .. | 120 | 122 | 125 | 128 | 130 | 133 | 135 | 138 | 140 | 143 | 145 | 147 | 150 | „ 2700 |
| | .. | .. | .. | 120 | 123 | 125 | 128 | 130 | 133 | 135 | 138 | 140 | 142 | 144 | 147 | „ 2800 |
| | .. | .. | .. | .. | 120 | 123 | 125 | 128 | 130 | 133 | 135 | 137 | 139 | 142 | 144 | „ 2900 |
| | .. | .. | .. | .. | .. | .. | 121 | 123 | 126 | 128 | 130 | 133 | 135 | 137 | 139 | „ 3000 |
| | .. | .. | .. | .. | .. | .. | 118 | 120 | 123 | 126 | 128 | 130 | 132 | 134 | 137 | „ 3100 |
| | .. | .. | .. | .. | .. | .. | .. | 118 | 121 | 123 | 126 | 128 | 130 | 132 | 134 | „ 3200 |
| | .. | .. | .. | .. | .. | .. | .. | .. | 119 | 121 | 124 | 126 | 128 | 130 | 132 | „ 3300 |
| | .. | .. | .. | .. | .. | .. | .. | .. | .. | 119 | 122 | 124 | 126 | 128 | 130 | „ 3400 |
| | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 122 | 124 | 126 | 128 | „ 3500 |
| | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 122 | 124 | 126 | „ 3600 |
| | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 122 | 124 | „ 3700 |
| | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 122 | „ 3800 |
| | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | „ 3900 |
| | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | „ 4000 |

TABLE No. 17.—TABLE of VELOCITIES in feet per minute in EGG-SHAPED

| Inclination. | Size, 1′ 0″ × 1′ 6″. | Size, 1′ 2″ × 1′ 9″. | Size, 1′ 4″ × 2′ 0″. | Size, 1′ 6″ × 2′ 3″. | Size, 1′ 8″ × 2′ 6″. | Size, 1′ 10″ × 2′ 9″. | Size, 2′ 0″ × 3′ 0″. | Size, 2′ 2″ × 3′ 3″. | Size, 2′ 4″ × 3′ 6″. | Size, 2′ 6″ × 3′ 9″. | Size, 2′ 8″ × 4′ 0″. | Size, 2′ 10″ × 4′ 3″. | Size, 3′ 0″ × 4′ 6″. | Size, 3′ 2″ × 4′ 9″. | Size, 3′ 4″ × 5′ 0″. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 in 100 | 344 | 371 | 396 | 420 | 441 | 462 | 483 | | | | | | | | |
| „ 110 | 328 | 354 | 378 | 401 | 421 | 441 | 462 | | | | | | | | |
| „ 120 | 314 | 339 | 362 | 384 | 404 | 423 | 442 | | | | | | | | |
| „ 130 | 301 | 325 | 348 | 369 | 388 | 407 | 425 | | | | | | | | |
| „ 140 | 290 | 314 | 336 | 356 | 374 | 392 | 410 | | | | | | | | |
| „ 150 | 280 | 303 | 324 | 344 | 362 | 379 | 396 | | | | | | | | |
| „ 160 | 271 | 293 | 314 | 333 | 351 | 368 | 384 | | | | | | | | |
| „ 170 | 262 | 284 | 304 | 323 | 340 | 357 | 373 | | | | | | | | |
| „ 180 | 254 | 275 | 295 | 314 | 330 | 347 | 363 | | | | | | | | |
| „ 190 | 247 | 268 | 287 | 305 | 321 | 337 | 353 | | | | | | | | |
| „ 200 | 241 | 261 | 280 | 298 | 314 | 329 | 344 | 358 | 371 | 384 | 396 | 408 | 420 | 431 | 442 |
| „ 250 | 214 | 232 | 249 | 265 | 280 | 294 | 307 | 320 | 332 | 344 | 355 | 366 | 377 | 387 | 397 |
| „ 300 | 194 | 211 | 226 | 241 | 255 | 268 | 280 | 292 | 303 | 314 | 324 | 334 | 344 | 353 | 362 |
| „ 350 | 179 | 194 | 208 | 222 | 235 | 247 | 258 | 269 | 280 | 290 | 300 | 309 | 318 | 327 | 336 |
| „ 400 | 167 | 181 | 194 | 207 | 219 | 230 | 241 | 251 | 261 | 271 | 280 | 289 | 297 | 305 | 313 |
| „ 450 | 157 | 170 | 183 | 195 | 206 | 216 | 226 | 236 | 245 | 254 | 263 | 272 | 280 | 288 | 296 |
| „ 500 | 148 | 161 | 173 | 184 | 195 | 205 | 214 | 223 | 232 | 241 | 249 | 257 | 265 | 273 | 280 |
| „ 550 | 141 | 153 | 164 | 175 | 185 | 195 | 204 | 212 | 221 | 229 | 237 | 245 | 252 | 259 | 266 |
| „ 600 | 134 | 146 | 157 | 167 | 176 | 186 | 195 | 203 | 211 | 219 | 226 | 233 | 240 | 247 | 254 |
| „ 650 | 128 | 139 | 150 | 160 | 169 | 178 | 187 | 195 | 203 | 210 | 217 | 224 | 231 | 237 | 243 |
| „ 700 | 123 | 134 | 144 | 153 | 162 | 171 | 179 | 187 | 195 | 202 | 209 | 216 | 222 | 228 | 234 |
| „ 750 | 119 | 129 | 139 | 148 | 156 | 165 | 173 | 181 | 188 | 195 | 201 | 208 | 214 | 220 | 226 |
| „ 800 | .. | 125 | 134 | 143 | 151 | 159 | 167 | 175 | 182 | 188 | 194 | 201 | 207 | 213 | 219 |
| „ 850 | .. | 121 | 130 | 138 | 146 | 154 | 162 | 169 | 176 | 182 | 188 | 194 | 200 | 206 | 212 |
| „ 900 | .. | .. | 126 | 134 | 142 | 149 | 157 | 164 | 170 | 176 | 182 | 188 | 194 | 200 | 206 |
| „ 950 | .. | .. | 122 | 130 | 138 | 145 | 152 | 159 | 165 | 171 | 177 | 183 | 189 | 194 | 200 |
| „ 1000 | .. | .. | 119 | 127 | 134 | 141 | 148 | 155 | 161 | 167 | 173 | 179 | 184 | 189 | 195 |
| „ 1100 | .. | .. | .. | 120 | 127 | 134 | 141 | 147 | 153 | 159 | 164 | 170 | 175 | 180 | 185 |
| „ 1200 | .. | .. | .. | .. | 122 | 128 | 134 | 140 | 146 | 152 | 157 | 162 | 167 | 172 | 177 |
| „ 1300 | .. | .. | .. | .. | .. | 123 | 129 | 134 | 140 | 145 | 150 | 155 | 160 | 165 | 169 |
| „ 1400 | .. | .. | .. | .. | .. | 119 | 124 | 129 | 134 | 139 | 144 | 149 | 153 | 158 | 162 |
| „ 1500 | .. | .. | .. | .. | .. | .. | 120 | 124 | 129 | 134 | 139 | 144 | 148 | 153 | 157 |
| „ 1600 | .. | .. | .. | .. | .. | .. | .. | 120 | 124 | 129 | 134 | 139 | 143 | 147 | 151 |
| „ 1700 | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 125 | 129 | 134 | 138 | 142 | 146 |
| „ 1800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 121 | 125 | 130 | 134 | 138 | 142 |
| „ 1900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 122 | 126 | 130 | 134 | 138 |
| „ 2000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 119 | 123 | 126 | 130 | 134 |
| „ 2100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 123 | 127 | 130 |
| „ 2200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 124 | 127 |
| „ 2300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 121 | 124 |
| „ 2400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 121 |
| „ 2500 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 119 |
| „ 2600 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3500 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3600 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |

**Sewers, when running two-thirds full at Various Rates of Inclination.**

| Size, 3′ 6″ × 5′ 3″. | Size, 3′ 8″ × 5′ 6″. | Size, 3′ 10″ × 5′ 9″. | Size, 4′ 0″ × 6′ 0″. | Size, 4′ 2″ × 6′ 3″. | Size, 4′ 4″ × 6′ 6″. | Size, 4′ 6″ × 6′ 9″. | Size, 4′ 8″ × 7′ 0″. | Size, 4′ 10″ × 7′ 3″. | Size, 5′ 0″ × 7′ 6″. | Size, 5′ 2″ × 7′ 9″. | Size, 5′ 4″ × 8′ 0″. | Size, 5′ 6″ × 8′ 3″. | Size, 5′ 8″ × 8′ 6″. | Size, 5′ 10″ × 8′ 9″. | Size, 6′ 0″ × 9′ 0″. | Inclination. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | 1 in 100 |
| | | | | | | | | | | | | | | | | „ 110 |
| | | | | | | | | | | | | | | | | „ 120 |
| | | | | | | | | | | | | | | | | „ 130 |
| | | | | | | | | | | | | | | | | „ 140 |
| | | | | | | | | | | | | | | | | „ 150 |
| | | | | | | | | | | | | | | | | „ 160 |
| | | | | | | | | | | | | | | | | „ 170 |
| | | | | | | | | | | | | | | | | „ 180 |
| | | | | | | | | | | | | | | | | „ 190 |
| 453 | 463 | 473 | 483 | 493 | 503 | 512 | 521 | 530 | 538 | 546 | 554 | 562 | 570 | 578 | 585 | „ 200 |
| 407 | 416 | 425 | 434 | 443 | 452 | 460 | 468 | 476 | 484 | 491 | 498 | 506 | 513 | 520 | 527 | „ 250 |
| 371 | 380 | 389 | 397 | 405 | 413 | 421 | 428 | 435 | 442 | 449 | 456 | 463 | 470 | 477 | 483 | „ 300 |
| 344 | 352 | 360 | 368 | 376 | 383 | 390 | 397 | 404 | 411 | 417 | 423 | 429 | 436 | 442 | 448 | „ 350 |
| 321 | 329 | 337 | 344 | 351 | 358 | 365 | 372 | 378 | 384 | 390 | 396 | 402 | 408 | 414 | 420 | „ 400 |
| 303 | 310 | 317 | 324 | 331 | 338 | 345 | 351 | 357 | 363 | 369 | 374 | 380 | 385 | 391 | 396 | „ 450 |
| 287 | 294 | 300 | 307 | 314 | 321 | 327 | 333 | 339 | 344 | 350 | 355 | 361 | 366 | 371 | 376 | „ 500 |
| 272 | 280 | 286 | 293 | 299 | 305 | 311 | 317 | 323 | 328 | 333 | 338 | 344 | 349 | 354 | 359 | „ 550 |
| 261 | 268 | 274 | 280 | 286 | 292 | 298 | 304 | 309 | 314 | 319 | 324 | 329 | 334 | 339 | 344 | „ 600 |
| 250 | 256 | 262 | 268 | 274 | 280 | 286 | 292 | 297 | 302 | 307 | 312 | 316 | 321 | 326 | 331 | „ 650 |
| 240 | 246 | 252 | 258 | 264 | 270 | 275 | 280 | 285 | 290 | 295 | 300 | 304 | 309 | 313 | 318 | „ 700 |
| 232 | 238 | 243 | 249 | 255 | 260 | 265 | 270 | 275 | 279 | 284 | 289 | 293 | 298 | 302 | 307 | „ 750 |
| 224 | 230 | 235 | 241 | 246 | 251 | 256 | 261 | 266 | 270 | 275 | 280 | 284 | 289 | 293 | 297 | „ 800 |
| 217 | 223 | 228 | 233 | 238 | 243 | 248 | 253 | 258 | 262 | 267 | 271 | 275 | 280 | 284 | 288 | „ 850 |
| 211 | 216 | 221 | 226 | 231 | 236 | 241 | 246 | 250 | 254 | 259 | 263 | 267 | 272 | 276 | 280 | „ 900 |
| 205 | 210 | 215 | 220 | 225 | 230 | 234 | 239 | 243 | 247 | 252 | 256 | 260 | 264 | 268 | 272 | „ 950 |
| 200 | 205 | 210 | 214 | 219 | 224 | 228 | 232 | 236 | 240 | 245 | 249 | 253 | 257 | 261 | 265 | „ 1000 |
| 190 | 195 | 199 | 203 | 208 | 213 | 217 | 221 | 225 | 229 | 233 | 237 | 241 | 244 | 248 | 252 | „ 1100 |
| 181 | 186 | 190 | 194 | 199 | 203 | 207 | 211 | 215 | 219 | 222 | 226 | 230 | 233 | 237 | 240 | „ 1200 |
| 173 | 178 | 182 | 186 | 191 | 195 | 199 | 202 | 206 | 210 | 213 | 216 | 220 | 223 | 227 | 230 | „ 1300 |
| 167 | 171 | 175 | 179 | 183 | 187 | 191 | 194 | 198 | 202 | 205 | 208 | 212 | 215 | 219 | 222 | „ 1400 |
| 161 | 165 | 169 | 173 | 177 | 181 | 185 | 188 | 191 | 195 | 198 | 201 | 205 | 208 | 211 | 214 | „ 1500 |
| 155 | 159 | 163 | 167 | 171 | 175 | 178 | 182 | 185 | 188 | 191 | 194 | 198 | 201 | 204 | 207 | „ 1600 |
| 150 | 154 | 158 | 162 | 165 | 169 | 172 | 176 | 179 | 182 | 185 | 188 | 191 | 194 | 197 | 200 | „ 1700 |
| 146 | 149 | 153 | 157 | 160 | 164 | 167 | 171 | 174 | 177 | 179 | 182 | 186 | 189 | 191 | 194 | „ 1800 |
| 142 | 145 | 149 | 152 | 156 | 159 | 162 | 166 | 169 | 172 | 174 | 177 | 180 | 183 | 186 | 189 | „ 1900 |
| 138 | 141 | 145 | 148 | 152 | 155 | 158 | 161 | 164 | 167 | 170 | 173 | 176 | 178 | 181 | 184 | „ 2000 |
| 134 | 137 | 141 | 144 | 148 | 151 | 154 | 157 | 160 | 163 | 166 | 168 | 171 | 174 | 176 | 179 | „ 2100 |
| 131 | 134 | 137 | 140 | 144 | 147 | 150 | 153 | 156 | 159 | 162 | 164 | 167 | 170 | 172 | 175 | „ 2200 |
| 128 | 131 | 134 | 137 | 140 | 143 | 146 | 149 | 152 | 155 | 158 | 160 | 163 | 166 | 168 | 171 | „ 2300 |
| 125 | 128 | 131 | 134 | 137 | 140 | 143 | 146 | 148 | 151 | 154 | 156 | 159 | 162 | 164 | 167 | „ 2400 |
| 122 | 125 | 128 | 131 | 134 | 137 | 140 | 143 | 145 | 147 | 150 | 153 | 156 | 158 | 160 | 163 | „ 2500 |
| 120 | 122 | 125 | 128 | 131 | 134 | 137 | 140 | 142 | 144 | 147 | 150 | 153 | 155 | 157 | 159 | „ 2600 |
| .. | 120 | 123 | 126 | 129 | 132 | 134 | 137 | 139 | 141 | 144 | 147 | 150 | 152 | 154 | 156 | „ 2700 |
| .. | .. | 121 | 124 | 126 | 129 | 132 | 134 | 136 | 139 | 142 | 144 | 147 | 149 | 151 | 153 | „ 2800 |
| .. | .. | .. | 121 | 124 | 126 | 129 | 131 | 134 | 136 | 139 | 141 | 144 | 146 | 148 | 150 | „ 2900 |
| .. | .. | .. | 119 | 122 | 124 | 127 | 129 | 132 | 134 | 136 | 139 | 141 | 144 | 146 | 148 | „ 3000 |
| .. | .. | .. | .. | 120 | 122 | 125 | 127 | 129 | 131 | 134 | 136 | 138 | 141 | 143 | 145 | „ 3100 |
| .. | .. | .. | .. | .. | 120 | 123 | 125 | 127 | 129 | 132 | 134 | 136 | 138 | 141 | 143 | „ 3200 |
| .. | .. | .. | .. | .. | .. | 121 | 123 | 125 | 127 | 130 | 132 | 134 | 137 | 139 | 141 | „ 3300 |
| .. | .. | .. | .. | .. | .. | 119 | 121 | 123 | 125 | 128 | 130 | 132 | 134 | 136 | 138 | „ 3400 |
| .. | .. | .. | .. | .. | .. | .. | 119 | 121 | 123 | 126 | 128 | 130 | 132 | 134 | 136 | „ 3500 |
| .. | .. | .. | .. | .. | .. | .. | .. | 119 | 121 | 124 | 126 | 128 | 130 | 132 | 134 | „ 3600 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 122 | 124 | 126 | 128 | 130 | 132 | „ 3700 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 122 | 124 | 126 | 128 | 130 | „ 3800 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 122 | 124 | 126 | 128 | „ 3900 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 121 | 122 | 124 | 126 | „ 4000 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 119 | 121 | 123 | 125 | „ 4100 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 119 | 121 | 123 | „ 4200 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 122 | „ 4300 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | „ 4400 |

TABLE No. 18.—VELOCITIES in feet per minute in EGG-SHAPE

| Inclination. | Size, 1′ 0″ × 1′ 6″. | Size, 1′ 2″ × 1′ 9″. | Size, 1′ 4″ × 2′ 0″. | Size, 1′ 6″ × 2′ 3″. | Size, 1′ 8″ × 2′ 6″. | Size, 1′ 10″ × 2′ 9″. | Size, 2′ 0″ × 3′ 0″. | Size, 2′ 2″ × 3′ 3″. | Size, 2′ 4″ × 3′ 6″. | Size, 2′ 6″ × 3′ 9″. | Size, 2′ 8″ × 4′ 0″. | Size, 2′ 10″ × 4′ 3″. | Size, 3′ 0″ × 4′ 6″. | Size, 3′ 2″ × 4′ 9″. | Size, 3′ 4″ × 5′ 0″. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 in 100 | 277 | 300 | 321 | 341 | 359 | 377 | 394 | | | | | | | | |
| „ 110 | 264 | 286 | 306 | 325 | 342 | 359 | 376 | | | | | | | | |
| „ 120 | 252 | 273 | 292 | 311 | 328 | 344 | 360 | | | | | | | | |
| „ 130 | 241 | 262 | 280 | 298 | 314 | 330 | 345 | | | | | | | | |
| „ 140 | 232 | 252 | 270 | 287 | 303 | 318 | 333 | | | | | | | | |
| „ 150 | 224 | 243 | 260 | 277 | 292 | 307 | 321 | | | | | | | | |
| „ 160 | 217 | 235 | 252 | 268 | 283 | 297 | 311 | | | | | | | | |
| „ 170 | 210 | 227 | 244 | 260 | 274 | 288 | 302 | | | | | | | | |
| „ 180 | 204 | 221 | 237 | 252 | 266 | 280 | 293 | | | | | | | | |
| „ 190 | 198 | 215 | 230 | 245 | 258 | 272 | 285 | | | | | | | | |
| „ 200 | 193 | 209 | 224 | 238 | 251 | 264 | 277 | 289 | 300 | 311 | 321 | 331 | 341 | 350 | 359 |
| „ 250 | 171 | 186 | 199 | 212 | 224 | 236 | 247 | 257 | 267 | 277 | 286 | 295 | 304 | 313 | 321 |
| „ 300 | 155 | 169 | 181 | 193 | 204 | 214 | 224 | 234 | 243 | 252 | 261 | 269 | 277 | 285 | 293 |
| „ 350 | 143 | 155 | 166 | 177 | 187 | 197 | 207 | 216 | 224 | 232 | 240 | 248 | 256 | 263 | 270 |
| „ 400 | 133 | 144 | 155 | 165 | 175 | 184 | 193 | 201 | 209 | 216 | 224 | 231 | 238 | 245 | 252 |
| „ 450 | 125 | 135 | 145 | 155 | 164 | 173 | 181 | 189 | 196 | 203 | 210 | 217 | 224 | 230 | 237 |
| „ 500 | 118 | 128 | 137 | 146 | 155 | 163 | 171 | 179 | 186 | 193 | 199 | 206 | 212 | 218 | 224 |
| „ 550 | .. | 122 | 130 | 139 | 147 | 155 | 162 | 170 | 177 | 184 | 190 | 196 | 202 | 208 | 213 |
| „ 600 | .. | .. | 125 | 133 | 140 | 148 | 155 | 162 | 169 | 175 | 181 | 187 | 193 | 199 | 204 |
| „ 650 | .. | .. | 119 | 127 | 134 | 141 | 148 | 155 | 161 | 167 | 173 | 179 | 185 | 190 | 195 |
| „ 700 | .. | .. | .. | 122 | 129 | 136 | 143 | 149 | 155 | 161 | 167 | 172 | 177 | 182 | 187 |
| „ 750 | .. | .. | .. | 118 | 124 | 131 | 138 | 144 | 149 | 155 | 161 | 166 | 171 | 176 | 181 |
| „ 800 | .. | .. | .. | .. | 120 | 127 | 133 | 139 | 144 | 150 | 155 | 160 | 165 | 170 | 175 |
| „ 850 | .. | .. | .. | .. | .. | 123 | 129 | 135 | 140 | 145 | 150 | 155 | 160 | 165 | 169 |
| „ 900 | .. | .. | .. | .. | .. | 119 | 125 | 131 | 136 | 141 | 145 | 150 | 155 | 160 | 164 |
| „ 950 | .. | .. | .. | .. | .. | .. | 121 | 127 | 132 | 137 | 141 | 146 | 151 | 155 | 159 |
| „ 1000 | .. | .. | .. | .. | .. | .. | .. | 123 | 128 | 133 | 137 | 142 | 146 | 150 | 155 |
| „ 1100 | .. | .. | .. | .. | .. | .. | .. | .. | 121 | 126 | 130 | 135 | 139 | 143 | 147 |
| „ 1200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 124 | 129 | 133 | 137 | 141 |
| „ 1300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 119 | 123 | 127 | 131 | 135 |
| „ 1400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 118 | 122 | 126 | 130 |
| „ 1500 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 118 | 122 | 125 |
| „ 1600 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 118 | 120 |
| „ 1700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 1800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 1900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | . | .. | .. | .. | .. |
| „ 2000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2500 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2600 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3000 | | | | | | | | | | | | | | | |

WERS, when running one-third full at VARIOUS RATES of INCLINATION.

| Size, 2′ 8″ × 5′ 6″. | Size, 3′ 10″ × 5′ 9″. | Size, 4′ 0″ × 6′ 0″. | Size, 4′ 2″ × 6′ 3″. | Size, 4′ 4″ × 6′ 6″. | Size, 4′ 6″ × 6′ 9″. | Size, 4′ 8″ × 7′ 0″. | Size, 4′ 10″ × 7′ 3″. | Size, 5′ 0″ × 7′ 6″. | Size, 5′ 2″ × 7′ 9″. | Size, 5′ 4″ × 8′ 0″. | Size, 5′ 6″ × 8′ 3″. | Size, 5′ 8″ × 8′ 6″. | Size, 5′ 10″ × 8′ 9″. | Size, 6′ 0″ × 9′ 0″. | Inclination. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | 1 in 100 |
| | | | | | | | | | | | | | | | „ 110 |
| | | | | | | | | | | | | | | | „ 120 |
| | | | | | | | | | | | | | | | „ 130 |
| | | | | | | | | | | | | | | | „ 140 |
| | | | | | | | | | | | | | | | „ 150 |
| | | | | | | | | | | | | | | | „ 160 |
| | | | | | | | | | | | | | | | „ 170 |
| | | | | | | | | | | | | | | | „ 180 |
| | | | | | | | | | | | | | | | „ 190 |
| 377 | 385 | 393 | 401 | 409 | 417 | 424 | 431 | 438 | 445 | 452 | 459 | 466 | 473 | 479 | „ 200 |
| 337 | 345 | 352 | 359 | 366 | 373 | 380 | 387 | 393 | 399 | 406 | 412 | 418 | 424 | 430 | „ 250 |
| 307 | 314 | 321 | 328 | 334 | 341 | 347 | 353 | 359 | 365 | 371 | 377 | 382 | 388 | 393 | „ 300 |
| 284 | 291 | 297 | 303 | 309 | 315 | 321 | 326 | 332 | 338 | 343 | 349 | 354 | 359 | 364 | „ 350 |
| 265 | 271 | 277 | 283 | 289 | 294 | 300 | 305 | 311 | 316 | 321 | 326 | 331 | 336 | 341 | „ 400 |
| 249 | 255 | 261 | 266 | 272 | 277 | 282 | 287 | 293 | 298 | 303 | 307 | 312 | 316 | 321 | „ 450 |
| 236 | 242 | 247 | 252 | 257 | 262 | 267 | 272 | 277 | 282 | 287 | 291 | 296 | 300 | 304 | „ 500 |
| 224 | 230 | 235 | 240 | 245 | 249 | 254 | 259 | 264 | 269 | 273 | 277 | 282 | 286 | 290 | „ 550 |
| 214 | 219 | 224 | 229 | 234 | 238 | 243 | 248 | 252 | 257 | 261 | 265 | 269 | 273 | 277 | „ 600 |
| 205 | 210 | 215 | 220 | 224 | 228 | 233 | 238 | 242 | 246 | 250 | 254 | 258 | 262 | 266 | „ 650 |
| 197 | 202 | 207 | 212 | 216 | 220 | 224 | 228 | 232 | 236 | 240 | 244 | 248 | 252 | 256 | „ 700 |
| 190 | 195 | 199 | 204 | 208 | 212 | 216 | 220 | 224 | 228 | 232 | 236 | 240 | 244 | 247 | „ 750 |
| 184 | 188 | 192 | 197 | 201 | 205 | 209 | 213 | 217 | 221 | 225 | 228 | 232 | 235 | 238 | „ 800 |
| 178 | 182 | 186 | 191 | 195 | 199 | 203 | 206 | 210 | 214 | 218 | 221 | 225 | 228 | 231 | „ 850 |
| 172 | 176 | 180 | 185 | 189 | 193 | 197 | 200 | 204 | 208 | 211 | 214 | 218 | 221 | 224 | „ 900 |
| 167 | 171 | 175 | 179 | 183 | 187 | 191 | 194 | 198 | 202 | 205 | 208 | 212 | 215 | 218 | „ 950 |
| 163 | 167 | 171 | 175 | 179 | 182 | 186 | 189 | 193 | 197 | 200 | 203 | 206 | 209 | 212 | „ 1000 |
| 155 | 159 | 162 | 166 | 170 | 173 | 177 | 180 | 183 | 187 | 190 | 193 | 196 | 199 | 202 | „ 1100 |
| 148 | 152 | 155 | 159 | 162 | 165 | 169 | 172 | 175 | 178 | 181 | 184 | 187 | 190 | 193 | „ 1200 |
| 142 | 146 | 149 | 152 | 155 | 158 | 161 | 164 | 167 | 170 | 173 | 176 | 179 | 182 | 185 | „ 1300 |
| 136 | 140 | 143 | 146 | 149 | 152 | 155 | 158 | 161 | 164 | 167 | 169 | 172 | 175 | 177 | „ 1400 |
| 131 | 134 | 137 | 140 | 143 | 146 | 149 | 152 | 155 | 158 | 161 | 163 | 166 | 169 | 171 | „ 1500 |
| 126 | 129 | 132 | 135 | 138 | 141 | 144 | 147 | 150 | 153 | 155 | 157 | 160 | 163 | 165 | „ 1600 |
| 122 | 125 | 128 | 131 | 134 | 137 | 140 | 142 | 145 | 148 | 150 | 152 | 155 | 158 | 160 | „ 1700 |
| 119 | 122 | 124 | 127 | 130 | 133 | 136 | 138 | 140 | 143 | 145 | 148 | 150 | 153 | 155 | „ 1800 |
| .. | 119 | 121 | 124 | 126 | 129 | 132 | 134 | 136 | 139 | 141 | 144 | 146 | 148 | 150 | „ 1900 |
| .. | .. | 118 | 121 | 123 | 125 | 128 | 130 | 133 | 135 | 138 | 140 | 142 | 144 | 146 | „ 2000 |
| .. | .. | .. | .. | 120 | 122 | 125 | 127 | 129 | 132 | 134 | 136 | 138 | 140 | 142 | „ 2100 |
| .. | .. | .. | .. | .. | 119 | 122 | 124 | 126 | 129 | 131 | 133 | 135 | 137 | 139 | „ 2200 |
| .. | .. | .. | .. | .. | .. | 119 | 121 | 123 | 125 | 127 | 129 | 132 | 134 | 136 | „ 2300 |
| .. | .. | .. | .. | .. | .. | .. | .. | 120 | 122 | 124 | 126 | 129 | 131 | 133 | „ 2400 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | 119 | 121 | 123 | 126 | 128 | 130 | „ 2500 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 119 | 121 | 123 | 125 | 127 | „ 2600 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 119 | 121 | 123 | 124 | „ 2700 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 119 | 120 | 122 | „ 2800 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | „ 2900 |
| | | | | | | | | | | | | | | | „ 3000 |

# DISCHARGE OF SEWERS.

Historical notice of Hydraulics.

The science of Hydraulics, like many kindred sciences, has gradually advanced in improvement until it has reached a high degree of perfection. It had its origin in the days of antiquity, although it is not clear that the ancient Romans, and others, had any formulæ, similar to those now generally used by engineers, to guide them in the construction of their hydraulic works, but it is quite clear that the Romans were practically masters of the laws which govern the flow and discharge of water, as the regulations existing in ancient Rome for the distribution of water within the city bear conclusive testimony that they possessed a clear knowledge of these laws, and also were acquainted with expedients which might be used for fraudulently obtaining a supply of water greater than was contemplated by their regulations. No record has been handed down to posterity of any formulæ that may have been employed in designing those stupendous works for bringing a supply of water into those ancient cities, or for calculating the discharge of the sewers flowing from those cities, and if any such were used they have been lost. After the revival of scientific research, it was not until the fourteenth century that hydraulics came to be considered a branch of science. In the seventeenth century this science received a considerable amount of attention, and from that period it has progressed rapidly towards perfection. Castelli and Torricelli, pupils of Galileo, both contributed largely to the development of this science. The former published a work on rivers in 1628, the latter discovered that by abstracting all resistances the velocity of an escaping fluid from an orifice was equal to that which a

heavy body would acquire when falling in vacuo, and he argued that the acceleration in the velocity of streams was due to the slope of the surface of the water. From that period to the middle of the eighteenth century, the science of hydraulics was treated almost entirely as a theoretical deduction, but then commenced the era of experimental investigation. Professor Michelotti of Turin, and Abbé Bossut of Paris, ably represented this new era, but it was left to M. Chezy, in 1775, to reduce the laws of water in motion to simple algebraic formula. This formula, introduced nearly a century ago, is presented in a form to which all subsequent formulæ may be reduced. The formula is here given :—

Era of experimental researcl

M. CHEZY'S FORMULA.

Chezy's formula.

$$V = \sqrt{\frac{g\,h\,a}{A\,l\,p}} = B\sqrt{r\,s}.$$

$V$ = velocity in feet per second.
$g$ = 32·194.
$h$ = difference in level in whole distance $l$.
$l$ = length of limited portion of channel.
$a$ = area of cross-section.
$p$ = length of wetted perimeter.
$A$ = coefficient or measure of resistance.
$B$ = determined by experiment.
$r = \frac{a}{p}$ = hydraulic mean depth.
$s = \frac{h}{l}$ = sine of slope.

This formula has been adopted by a large number of authorities, the value of B differing somewhat. As for example :—

Value of coefficients by different authorities.

Beardmore, 94·2.
D'Aubisson, 95·6 for velocities over 2 feet.
Downing and Taylor, 100 for large and rapid rivers.
Eytelwein, 93·4.
Leslie, 68 for small rivers; 100 for large.
Neville, 92·3 for velocities under 1·5 foot per second, and 93·3 for greater velocities.
Stevenson, 69 for small streams; 96 for large streams.

The formula most generally used at the present day

Eytelwein's formula.

is that ascribed to Eytelwein, introduced in the early part of the present century. It is as follows:—

$$V = \cdot 9091 \sqrt{2Hr},$$

which by reduction can be put

$$V = 93 \cdot 4 \sqrt{rs}.$$

$$V^1 = 55 \sqrt{2Hr}.$$

H = fall in feet per mile.
V = velocity per second.
$V^1$ = velocity per minute.
$r$ = mean radius or hydraulic mean depth.
S = sine of slope.

Eytelwein found that the velocity per second nearly equals a mean proportional between the hydraulic mean depth and twice the fall in feet per mile. The formula used in preparing the several calculations in the Tables in this book is that of Weisbach, which is here given:—

Weisbach's formula.

$$h = \left(1 + e + c \times \frac{l}{d}\right) \frac{v^2}{2g}.$$

$$v = \frac{\sqrt{2gh}}{\sqrt{1 + e + c \times \frac{l}{d}}}.$$

$h$ = head of water in feet.
$l$ = length of pipe in feet.
$d$ = diameter of pipe in feet.
$v$ = velocity in feet per second.
$c$ = coefficient for friction in pipe.
$e$ = coefficient of resistance for entrance of water into pipe.

$$c = \cdot 01439 + \frac{\cdot 016921}{\sqrt{v}}.$$

The following Table gives the different values of $c$ for varying velocities:—

| $v$ | $c$ | $v$ | $c$ | $v$ | $c$ |
|---|---|---|---|---|---|
| ·1 | ·0679 | ·7 | ·0346 | 3 | ·0242 |
| ·2 | ·0522 | ·8 | ·0333 | 4 | ·0229 |
| ·3 | ·0453 | ·9 | ·0322 | 6 | ·0213 |
| ·4 | ·0411 | 1·0 | ·0313 | 8 | ·0204 |
| ·5 | ·0383 | 1·5 | ·0282 | 12 | ·0192 |
| ·6 | ·0362 | 2·0 | ·0263 | 20 | ·0182 |

$e$ is at an average = ·505, but may be reduced to ·08 by rounding off the inlet.

For $h = v$, and $1 : i$ = rate of inclination.

$$v = \frac{64 \cdot 38}{1505 + \frac{c v i}{d}}$$

It will be seen from this formula that different coefficients are used for varying velocities. It should be fully borne in mind by those carrying out works of sewerage that gravity is the sole cause of motion. The motion of the particles of water in the sewer is wholly due to the inclination of the surface. When a fluid is brought to rest its surface will be horizontal, and when the surface is in that position the action of gravity ceases and the fluid ceases to flow. But so soon as the surface becomes inclined motion recommences, although the bottom of the channel may be horizontal, or even have an inclination opposed to that of the flow of the water. Water flowing through a sewer is subject to certain accelerating forces, so that, if it did not encounter any resistance, it would descend with an accelerating speed, just the same as any heavy body falling through air or running down an inclined plane. But in a sewer, or channel, used for the conveyance of water, certain retarding forces are at work which are equal to and destroy the accelerating force at every moment. Resistance in the case of a sewer is that offered by the bed and sides of the channels. It is assumed by many authorities on hydraulics that the velocity is retarded, owing to the attraction of the particles of fluid in motion, by those particles of the fluid which adhere to the walls of the channel. If this is true the resistance of the flow of water depends, not so much upon the nature of the material composing the channel, as all materials more or less have an attraction for water, and in a channel a lamina of water is consequently spread over their surface. The experiments

Gravity sole cause of motion.

Retarding forces.

Resistance of different materials.

of Dubuat failed to show that there was any variation in the friction of water in channels of glass, lead, iron, or wood, so that for all practical purposes the nature of the materials of which a sewer is constructed need not be taken into consideration. That portion of the channel in a sewer or watercourse which is touched by the water is termed the wetted perimeter, and the greater the proportion of the wetted perimeter to the volume to be discharged the greater will be the resistance. Resistance is therefore in the inverse ratio to the section, and increases directly as the velocity. In all calculations of the discharge of water through sewers or channels, it is requisite to determine, with accuracy, the extent of the wetted perimeter, and also the sectional area of the water-way. By dividing the sectional area of the channel by the wetted perimeter, or the contour of the wetted channel, we get what is called "the mean hydraulic depth," or often, "the mean radius." In all circular sewers it is easy to determine the hydraulic mean depth, or mean radius, as the proportion between the wetted perimeter and the area, both when the sewer is running full or half full, is the same, and invariably equals one-fourth the diameter of the sewer. The hydraulic mean depth of egg-shaped sewers varies with the volume of water flowing through them, but when such sewers are of the usual proportion,* the hydraulic mean depth when running full is found by multiplying the transverse diameter by 0·2897; when running two-thirds full by 0·3157; and when running one-third full by 0·2066. The perimeter of an egg-shaped sewer when running full equals 3·9649 times the transverse diameter. When running two-thirds full it is equal to 2·3941 times the transverse diameter, and when running one-third full it is equal to 1·3747 times the transverse diameter of the sewer.

Wetted perimeter.

Hydraulic mean depth of sewers.

Hydraulic mean depth in circular sewers.

Hydraulic mean depth in egg-shaped sewers.

Perimeter of egg-shaped sewers.

* The proportion is given in the description of Table No. 12, page 54.

## DESCRIPTION OF TABLES RELATING TO THE DISCHARGE OF SEWERS, NUMBERING FROM 19 TO 24 INCLUSIVE.

Table No. 19. Table No. 19 gives the area, the circumference or perimeter, and the hydraulic mean depth of circular sewers varying in size from 4 inches to 10 feet in diameter. The discharge of any circular sewer may be arrived at by ascertaining the velocity as given in the explanation of Table No. 11, page 53, and multiplying it by the area in square feet, as given by this Table.

TABLE No. 19.—AREAS and HYDRAULIC MEAN DEPTHS of CIRCULAR SEWERS.

| Diam. | Area. | Circumference. | Hydraulic Mean Depth when running full. | Diam. | Area. | Circumference. | Hydraulic Mean Depth when running full. |
|---|---|---|---|---|---|---|---|
| ins. | square ft. | feet. | feet. | ins. | square ft. | feet. | feet. |
| 4 | 0·0872 | 1·0471 | ·0825 | 45 | 11·045 | 11·781 | ·9375 |
| 6 | 0·1963 | 1·5708 | ·125 | 48 | 12·566 | 12·566 | 1·00 |
| 8 | 0·3490 | 2·0942 | ·165 | 54 | 15·904 | 14·137 | 1·125 |
| 9 | 0·4418 | 2·3562 | ·1875 | 60 | 19·635 | 15·708 | 1·25 |
| 10 | 0·5454 | 2·6180 | ·2083 | 66 | 23·758 | 17·279 | 1·375 |
| 12 | 0·7854 | 3·1416 | ·250 | 72 | 28·274 | 18·850 | 1·50 |
| 15 | 1·227 | 3·927 | ·3125 | 78 | 33·183 | 20·420 | 1·625 |
| 18 | 1·767 | 4·712 | ·375 | 84 | 38·485 | 21·991 | 1·75 |
| 20 | 2·182 | 5·236 | ·4166 | 90 | 44·179 | 23·562 | 1·875 |
| 22 | 2·640 | 5·762 | ·4583 | 96 | 50·265 | 25·133 | 2·00 |
| 24 | 3·142 | 6·283 | ·500 | 102 | 56·745 | 26·704 | 2·125 |
| 30 | 4·909 | 7·854 | ·625 | 108 | 63·617 | 28·274 | 2·25 |
| 36 | 7·069 | 9·425 | ·750 | 114 | 70·882 | 29·845 | 2·375 |
| 40 | 8·727 | 10·472 | ·833 | 120 | 78·540 | 31·416 | 2·500 |

Table No. 20. Table No. 20 gives the area and hydraulic mean depth of egg-shaped sewers constructed of the usual proportions, or for sewers in which the transverse diameter is equal to two-thirds the vertical diameter, and in which the invert is struck with a radius of one-fourth that of the transverse diameter, the sides being struck with a radius equal to that of the vertical diameter of the sewer. The discharge of any sewer may be arrived at by multiplying the sectional area of the sewer, as given in this Table, by the velocity, which

may be arrived at from the explanation of Tables No. 12, 13, or 14, given at pages 54 and 55.

TABLE No. 20.—AREAS and HYDRAULIC MEAN DEPTHS of EGG-SHAPED SEWERS.

| Size of Sewer. | Sectional Area when running full. | Sectional Area when flowing ⅓rds vertical height. | Sectional Area when flowing ½rd vertical height. | Hydraulic Mean Depth flowing full. | Hydraulic Mean Depth flowing ⅓rds vertical height. | Hydraulic Mean Depth flowing ½rd vertical height. |
|---|---|---|---|---|---|---|
| ′ ″ ′ ″ | | | | | | |
| 1 0 × 1 6 | 1·1485 | 0·7558 | 0·2840 | 0·2897 | 0·3157 | 0·2066 |
| 1 2 × 1 9 | 1·15632 | 1·0287 | 0·3865 | 0·3380 | 0·3683 | 0·2410 |
| 1 4 × 2 0 | 2·0418 | 1·3436 | 0·5049 | 0·3863 | 0·4209 | 0·2755 |
| 1 6 × 2 3 | 2·5841 | 1·7005 | 0·6390 | 0·4345 | 0·4735 | 0·3099 |
| 1 8 × 2 6 | 3·1903 | 2·0994 | 0·7889 | 0·4828 | 0·5262 | 0·3443 |
| 1 10 × 2 9 | 3·8602 | 2·5402 | 0·9545 | 0·5311 | 0·5788 | 0·3786 |
| 2 0 × 3 0 | 4·5940 | 3·0232 | 1·1360 | 0·5794 | 0·6314 | 0·4132 |
| 2 2 × 3 3 | 5·3916 | 3·5480 | 1·3332 | 0·6277 | 0·6840 | 0·4476 |
| 2 4 × 3 6 | 6·2529 | 4·1149 | 1·5462 | 0·6760 | 0·7366 | 0·4820 |
| 2 6 × 3 9 | 7·1781 | 4·7237 | 1·7750 | 0·7242 | 0·7892 | 0·5165 |
| 2 8 × 4 0 | 8·1671 | 5·3746 | 2·0195 | 0·7725 | 0·8418 | 0·5409 |
| 2 10 × 4 3 | 9·2199 | 6·0674 | 2·2799 | 0·8208 | 0·8944 | 0·5852 |
| 3 0 × 4 6 | 10·3365 | 6·8022 | 2·5560 | 0·8691 | 0·9471 | 0·6198 |
| 3 2 × 4 9 | 11·5169 | 7·5790 | 2·8479 | 0·9174 | 0·9997 | 0·6542 |
| 3 4 × 5 0 | 12·7611 | 8·3978 | 3·1556 | 0·9657 | 1·0523 | 0·6887 |
| 3 6 × 5 3 | 14·0691 | 9·2585 | 3·4790 | 1·0139 | 1·1049 | 0·7231 |
| 3 8 × 5 6 | 15·4099 | 10·1613 | 3·8182 | 1·0622 | 1·1576 | 0·7575 |
| 3 10 × 5 9 | 16·8766 | 11·1061 | 4·1732 | 1·1105 | 1·2102 | 0·7920 |
| 4 0 × 6 0 | 18·3760 | 12·0928 | 4·5440 | 1·1588 | 1·2628 | 0·8264 |
| 4 2 × 6 3 | 19·9392 | 13·1215 | 4·9306 | 1·2071 | 1·3154 | 0·8608 |
| 4 4 × 6 6 | 21·5663 | 14·1922 | 5·3329 | 1·2554 | 1·3680 | 0·8952 |
| 4 6 × 6 9 | 23·2571 | 15·3049 | 5·7510 | 1·3036 | 1·4206 | 0·9297 |
| 4 8 × 7 0 | 25·0117 | 16·4596 | 6·1849 | 1·3519 | 1·4733 | 0·9641 |
| 4 10 × 7 3 | 26·8302 | 17·6563 | 6·6346 | 1·4002 | 1·5258 | 0·9986 |
| 5 0 × 7 6 | 28·7125 | 18·8950 | 7·1000 | 1·4485 | 1·5785 | 1·0330 |
| 5 2 × 7 9 | 30·6649 | 20·1757 | 7·5812 | 1·4968 | 1·6311 | 1·0675 |
| 5 4 × 8 0 | 32·6684 | 21·4983 | 8·0782 | 1·5451 | 1·6836 | 1·1019 |
| 5 6 × 8 3 | 34·7421 | 22·8629 | 8·5910 | 1·5933 | 1·7363 | 1·1363 |
| 5 8 × 8 6 | 36·8796 | 24·2696 | 9·1196 | 1·6416 | 1·7890 | 1·1707 |
| 5 10 × 8 9 | 39·0809 | 25·7182 | 9·6639 | 1·6899 | 1·8415 | 1·2052 |
| 6 0 × 9 0 | 41·3460 | 27·2088 | 10·2240 | 1·7382 | 1·8942 | 1·2396 |

Table No. 21. Table No. 21 gives the discharge in cube feet per minute of circular sewers, varying in size from 4 inches to 10 feet in diameter, when laid at inclinations varying from 1 in 50 to 1 in 6000. In preparing this Table, the length of sewer taken into consideration is the same as given in the description of Table No. 15, page 55. For all practical purposes, this Table may be taken as correct, but in cases in which extreme accuracy

is required, the actual discharge may be arrived at in the way pointed out in the description of Table No. 19. It may be noted that the point at which the discharge terminates in this Table, represents the least inclination (giving a velocity of 120 feet per minute) which should be adopted for any sewer intended to be self-cleansing, consequently it will be seen at a glance, that when a sewer of a certain size is laid at the greatest inclination that circumstances allow, to make it self-cleansing, and the discharge required is not sufficient, then a larger sewer must be adopted.

Table No. 22 gives the discharge in cube feet per minute for egg-shaped sewers when running full. The discharge is calculated for sewers varying in size from 1ft. x 1ft. 6in., to 6ft. x 9ft., when laid at inclinations varying from 1 in 100 to 1 in 4000. Table No. 22.

Table No. 23 is similar to Table No. 22, only that it is calculated for sewers when running two-thirds full. Table No. 23.

Table No. 24 is similar to Table No. 22, except that the calculations are made for sewers when running one-third full. Table No. 24.

## TABLE No. 21.—DISCHARGE in Cube Feet per Minute for CIRCULAR SEWERS,

| Inclination. | Size, 4″. | Size, 6″. | Size, 8″. | Size, 9″. | Size, 10″. | Size, 12″. | Size, 15″. | Size, 18″. | Size, 20″. | Size, 22″. | Size, 24″. | Size, 30″. | Size, 36″. | Size, 40″. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 in 50 | 21·48 | 60·17 | 123·5 | 165·7 | 214·7 | 339·1 | 590·2 | 927·7 | | | | | | |
| „ 60 | 19·73 | 54·68 | 112·7 | 151·6 | 196·7 | 310·1 | 539·9 | 849·9 | | | | | | |
| „ 70 | 18·25 | 50·37 | 104·0 | 140·1 | 182·0 | 287·3 | 500·6 | 788·1 | | | | | | |
| „ 80 | 16·94 | 46·84 | 97·02 | 130·8 | 170·0 | 268·5 | 468·7 | 738·6 | | | | | | |
| „ 90 | 15·89 | 44·10 | 91·44 | 123·3 | 160·2 | 252·8 | 441·7 | 696·2 | | | | | | |
| „ 100 | 15·02 | 41·75 | 86·55 | 116·7 | 152·1 | 240·2 | 419·6 | 660·9 | 859·7 | 1090 | 1357 | | | |
| „ 110 | 14·23 | 39·59 | 82·36 | 110·9 | 144·4 | 228·4 | 400·0 | 630·8 | 820·4 | 1043 | 1298 | | | |
| „ 120 | 13·53 | 37·83 | 78·52 | 106·1 | 137·9 | 218·2 | 382·8 | 604·3 | 785·5 | 997·9 | 1241 | | | |
| „ 130 | 13·01 | 36·46 | 75·38 | 101·7 | 132·4 | 209·6 | 366·9 | 579·6 | 755·0 | 958·3 | 1191 | | | |
| „ 140 | 12·48 | 34·89 | 72·59 | 97·68 | 127·0 | 201·7 | 353·4 | 558·4 | 728·8 | 924·0 | 1147 | | | |
| „ 150 | 12·05 | 33·71 | 70·15 | 94·15 | 122·6 | 194·7 | 341·1 | 540·7 | 702·6 | 892·3 | 1109 | | | |
| „ 160 | 11·61 | 32·54 | 67·71 | 91·05 | 118·8 | 188·4 | 330·1 | 523·0 | 680·8 | 863·3 | 1075 | | | |
| „ 170 | 11·26 | 31·36 | 65·61 | 87·96 | 115·0 | 182·1 | 320·2 | 507·1 | 661·1 | 836·9 | 1043 | | | |
| „ 180 | 10·91 | 30·38 | 63·52 | 85·31 | 111·7 | 176·6 | 310·4 | 491·2 | 641.5 | 813·1 | 1012 | | | |
| „ 190 | 10·56 | 29·60 | 61·77 | 83·10 | 108·5 | 171·9 | 301·8 | 477·1 | 624·1 | 792·0 | 983·4 | | | |
| „ 200 | 10·36 | 28·81 | 60·03 | 80·89 | 105·7 | 167·2 | 293·3 | 464·7 | 606·6 | 770·9 | 958·3 | 1679 | 2651 | 3448 |
| „ 250 | .. | 25·68 | 53·40 | 72·05 | 93·74 | 148·4 | 261·4 | 413·5 | 539·0 | 686·4 | 854·6 | 1497 | 2368 | 3082 |
| „ 300 | .. | 23·13 | 48·16 | 64·97 | 85·03 | 135·0 | 236·8 | 376·4 | 491·0 | 625·7 | 779·2 | 1365 | 2156 | 2811 |
| „ 350 | .. | .. | 44·32 | 59·67 | 77·93 | 124·0 | 218·4 | 346·3 | 451·7 | 575·5 | 716·4 | 1257 | 1993 | 2602 |
| „ 400 | .. | .. | 41·18 | 55·69 | 72·49 | 115·4 | 203·7 | 323·4 | 421·1 | 535·9 | 669·2 | 1173 | 1859 | 2427 |
| „ 450 | .. | .. | .. | 52·16 | 68·13 | 108·3 | 191·4 | 303·9 | 397·1 | 504·2 | 628·4 | 1105 | 1746 | 2278 |
| „ 500 | .. | .. | .. | .. | 64·31 | 102·05 | 180·4 | 286·3 | 375·3 | 477·8 | 593·8 | 1046 | 1654 | 2156 |
| „ 550 | .. | .. | .. | .. | .. | 97·34 | 171·8 | 272·1 | 355·7 | 454·1 | 565·6 | 996·5 | 1576 | 2052 |
| „ 600 | .. | .. | .. | .. | .. | 92·63 | 164·4 | 259·7 | 340·4 | 433·0 | 540·4 | 952·3 | 1506 | 1964 |
| „ 650 | .. | .. | .. | .. | .. | .. | 157·1 | 249·1 | 325·1 | 414·5 | 518·4 | 913·1 | 1442 | 1886 |
| „ 700 | .. | .. | .. | .. | .. | .. | 150·9 | 238·5 | 312·0 | 398·6 | 496·4 | 878·7 | 1385 | 1816 |
| „ 750 | .. | .. | .. | .. | .. | .. | 144·8 | 229·7 | 301·1 | 382·8 | 477·6 | 844·3 | 1336 | 1755 |
| „ 800 | .. | .. | .. | .. | .. | .. | .. | 222·6 | 290·2 | 369·6 | 461·9 | 814·9 | 1294 | 1694 |
| „ 850 | .. | .. | .. | .. | .. | .. | .. | 215·6 | 281·5 | 359·0 | 446·2 | 790·3 | 1251 | 1641 |
| „ 900 | .. | .. | .. | .. | .. | .. | .. | 208·5 | 272·7 | 348·5 | 433·6 | 765·8 | 1216 | 1589 |
| „ 950 | .. | .. | .. | .. | .. | .. | .. | .. | 264·0 | 337·9 | 421·0 | 741·3 | 1181 | 1545 |
| „ 1000 | .. | .. | .. | .. | .. | .. | .. | .. | 257·5 | 327·4 | 408·5 | 721·6 | 1145 | 1502 |
| „ 1100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 311·5 | 389·6 | 687·3 | 1089 | 1423 |
| „ 1200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 370·8 | 652·9 | 1039 | 1362 |
| „ 1300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 623·4 | 996·7 | 1301 |
| „ 1400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 598·9 | 954·3 | 1248 |
| „ 1500 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 579·3 | 919·0 | 1205 |
| „ 1600 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 890·7 | 1161 |
| „ 1700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 862·4 | 1126 |
| „ 1800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 834·1 | 1091 |
| „ 1900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 1056 |
| „ 2000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 1030 |
| „ 2100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2500 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2600 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3500 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3600 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4500 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4600 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 5000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 5100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 5400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 5700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 6000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |

ing full and constructed at VARIOUS RATES of INCLINATION.

| Size, 54". | Size, 60". | Size, 66". | Size, 72". | Size, 78". | Size, 84". | Size, 90". | Size, 96". | Size, 102". | Size, 108". | Size, 114". | Size, 120". | Inclination. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | 1 in 50 |
| | | | | | | | | | | | | „ 60 |
| | | | | | | | | | | | | „ 70 |
| | | | | | | | | | | | | „ 80 |
| | | | | | | | | | | | | „ 90 |
| | | | | | | | | | | | | „ 100 |
| | | | | | | | | | | | | „ 110 |
| | | | | | | | | | | | | „ 120 |
| | | | | | | | | | | | | „ 130 |
| | | | | | | | | | | | | „ 140 |
| | | | | | | | | | | | | „ 150 |
| | | | | | | | | | | | | „ 160 |
| | | | | | | | | | | | | „ 170 |
| | | | | | | | | | | | | „ 180 |
| 7288 | 9444 | 11950 | 14816 | | | | | | | | | „ 190 |
| 6537 | 8503 | 10762 | 13345 | | | | | | | | | „ 200 |
| 5964 | 7756 | 9836 | 12186 | | | | | | | | | „ 250 |
| 5519 | 7186 | 9123 | 11310 | | | | | | | | | „ 300 |
| 5169 | 6715 | 8529 | 10603 | | | | | | | | | „ 350 |
| 4883 | 6342 | 8054 | 10009 | | | | | | | | | „ 400 |
| 4613 | 6008 | 7626 | 9472 | 11581 | 13932 | 16567 | 19452 | 22641 | 26083 | 29841 | 33929 | „ 450 |
| 4380 | 5714 | 7246 | 9019 | 11017 | 13239 | 15728 | 18497 | 21506 | 24811 | 28424 | 32358 | „ 500 |
| 4183 | 5458 | 6937 | 8624 | 10552 | 12700 | 15109 | 17744 | 20655 | 23856 | 27290 | 31023 | „ 550 |
| 4006 | 5243 | 6652 | 8284 | 10121 | 12200 | 14535 | 17090 | 19861 | 22902 | 26226 | 29845 | „ 600 |
| 3865 | 5046 | 6415 | 7973 | 9756 | 11738 | 13961 | 16437 | 19123 | 22075 | 25305 | 28746 | „ 650 |
| 3737 | 4869 | 6177 | 7691 | 9424 | 11353 | 13475 | 15834 | 18442 | 21312 | 24454 | 27803 | „ 700 |
| 3624 | 4693 | 5963 | 7436 | 9092 | 10968 | 13033 | 15331 | 17875 | 20612 | 23604 | 26861 | „ 750 |
| 3483 | 4536 | 5773 | 7210 | 8827 | 10622 | 12635 | 14878 | 17307 | 19976 | 22895 | 25997 | „ 800 |
| 3388 | 4418 | 5607 | 6984 | 8561 | 10314 | 12282 | 14426 | 16796 | 19403 | 22257 | 25290 | „ 850 |
| 3292 | 4300 | 5464 | 6786 | 8329 | 10045 | 11928 | 14024 | 16342 | 18894 | 21619 | 24583 | „ 900 |
| 3213 | 4182 | 5322 | 6616 | 8097 | 9775 | 11619 | 13672 | 15945 | 18385 | 21052 | 23955 | „ 1000 |
| 3054 | 3986 | 5060 | 6305 | 7698 | 9275 | 11045 | 13019 | 15208 | 17558 | 20060 | 22777 | „ 1100 |
| 2910 | 3790 | 4823 | 6022 | 7367 | 8890 | 10603 | 12466 | 14527 | 16795 | 19209 | 21834 | „ 1200 |
| 2783 | 3632 | 4633 | 5768 | 7068 | 8544 | 10161 | 11963 | 13903 | 16095 | 18429 | 20970 | „ 1300 |
| 2672 | 3495 | 4443 | 5542 | 6803 | 8197 | 9764 | 11511 | 13392 | 15459 | 17720 | 20185 | „ 1400 |
| 2576 | 3377 | 4300 | 5344 | 6537 | 7890 | 9410 | 11109 | 12938 | 14950 | 17083 | 19478 | „ 1500 |
| 2497 | 3259 | 4158 | 5174 | 6338 | 7659 | 9101 | 10706 | 12484 | 14441 | 16515 | 18771 | „ 1600 |
| 2417 | 3161 | 4015 | 5004 | 6139 | 7428 | 8836 | 10355 | 12087 | 13996 | 16019 | 18221 | „ 1700 |
| 2338 | 3063 | 3896 | 4863 | 5973 | 7197 | 8571 | 10053 | 11746 | 13550 | 15523 | 17671 | „ 1800 |
| 2274 | 2965 | 3777 | 4722 | 5774 | 6966 | 8306 | 9751 | 11406 | 13169 | 15098 | 17200 | „ 1900 |
| 2211 | 2886 | 3682 | 4580 | 5608 | 6773 | 8085 | 9500 | 11065 | 12787 | 14673 | 16729 | „ 2000 |
| 2147 | 2808 | 3587 | 4467 | 5475 | 6619 | 7864 | 9249 | 10782 | 12469 | 14318 | 16336 | „ 2100 |
| 2099 | 2749 | 3492 | 4354 | 5342 | 6465 | 7687 | 9048 | 10554 | 12214 | 14035 | 15944 | „ 2200 |
| 2052 | 2670 | 3397 | 4241 | 5210 | 6312 | 7510 | 8847 | 10328 | 11896 | 13680 | 15551 | „ 2300 |
| 2004 | 2611 | 3326 | 4156 | 5110 | 6158 | 7334 | 8646 | 10101 | 11642 | 13326 | 15158 | „ 2400 |
| 1956 | 2553 | 3255 | 4071 | 4977 | 6004 | 7157 | 8444 | 9874 | 11377 | 13042 | 14844 | „ 2500 |
| 1908 | 2513 | 3207 | 3987 | 4878 | 5888 | 7024 | 8294 | 9647 | 11133 | 12759 | 14530 | „ 2600 |
| 1877 | 2454 | 3136 | 3902 | 4778 | 5773 | 6892 | 8093 | 9420 | 10878 | 12475 | 14216 | „ 2700 |
| .. | 2415 | 3065 | 3817 | 4679 | 5657 | 6759 | 7942 | 9249 | 10688 | 12263 | 13980 | „ 2800 |
| .. | 2356 | 2994 | 3732 | 4579 | 5542 | 6627 | 7791 | 9079 | 10497 | 12050 | 13744 | „ 2900 |
| .. | 2317 | 2946 | 3676 | 4513 | 5465 | 6538 | 7691 | 8966 | 10370 | 11908 | 13569 | „ 3000 |
| .. | .. | 2898 | 3619 | 4447 | 5349 | 6406 | 7540 | 8795 | 10179 | 11696 | 13273 | „ 3100 |
| .. | .. | 2851 | 3563 | 4380 | 5272 | 6273 | 7389 | 8625 | 9988 | 11483 | 13038 | „ 3200 |
| .. | .. | 2803 | 3506 | 4314 | 5195 | 6185 | 7288 | 8512 | 9861 | 11270 | 12802 | „ 3300 |
| .. | .. | .. | 3449 | 4247 | 5119 | 6097 | 7188 | 8398 | 9733 | 11128 | 12645 | „ 3400 |
| .. | .. | .. | 3393 | 4181 | 5042 | 6008 | 7087 | 8285 | 9543 | 10916 | 12409 | „ 3500 |
| .. | .. | .. | 3336 | 4115 | 4965 | 5920 | 6987 | 8171 | 9415 | 10774 | 12252 | „ 3600 |
| .. | .. | .. | .. | 4048 | 4888 | 5832 | 6886 | 8001 | 9224 | 10561 | 12017 | „ 3700 |
| .. | .. | .. | .. | 3982 | 4811 | 5743 | 6786 | 7888 | 9097 | 10420 | 11860 | „ 3800 |
| .. | .. | .. | .. | 3916 | 4734 | 5655 | 6685 | 7774 | 8970 | 10278 | 11702 | „ 3900 |
| .. | .. | .. | .. | .. | 4657 | 5567 | 6585 | 7661 | 8843 | 10136 | 11545 | „ 4000 |
| .. | .. | .. | .. | .. | 4580 | 5478 | 6484 | 7547 | 8716 | 9994 | 11388 | „ 4100 |
| .. | .. | .. | .. | .. | 4541 | 5434 | 6384 | 7434 | 8588 | 9853 | 11231 | „ 4200 |
| .. | .. | .. | .. | .. | .. | 5346 | 6283 | 7330 | 8461 | 9711 | 11074 | „ 4300 |
| .. | .. | .. | .. | .. | .. | 5301 | 6233 | 7263 | 8397 | 9640 | 10966 | „ 4400 |
| .. | .. | .. | .. | .. | .. | 5213 | 6132 | 7150 | 8270 | 9498 | 10838 | „ 4500 |
| .. | .. | .. | .. | .. | .. | .. | 6052 | 7093 | 8207 | 9427 | 10681 | „ 4600 |
| .. | .. | .. | .. | .. | .. | .. | 5982 | 6980 | 8079 | 9286 | 10524 | „ 4700 |
| .. | .. | .. | .. | .. | .. | .. | 5931 | 6923 | 8016 | 9215 | 10446 | „ 4800 |
| .. | .. | .. | .. | .. | .. | .. | .. | 6809 | 7889 | 9073 | 10289 | „ 4900 |
| .. | .. | .. | .. | .. | .. | .. | .. | 6753 | 7825 | 9002 | 10210 | „ 5000 |
| .. | .. | .. | .. | .. | .. | .. | .. | 6696 | 7761 | 8931 | 10132 | „ 5100 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | 7507 | 8648 | 9818 | „ 5400 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 8364 | 9503 | „ 5700 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 9268 | „ 6000 |

TABLE No. 22.—DISCHARGE in cube feet per minute for EGG-SHAPED SEWERS

| Inclination. | Size, 1′ 0″ × 1′ 6″. | Size, 1′ 2″ × 1′ 9″. | Size, 1′ 4″ × 2′ 0″. | Size, 1′ 6″ × 2′ 3″. | Size, 1′ 8″ × 2′ 6″. | Size, 1′ 10″ × 2′ 9″. | Size, 2′ 0″ × 3′ 0″. | Size, 2′ 2″ × 3′ 3″. | Size, 2′ 4″ × 3′ 6″. | Size, 2′ 6″ × 3′ 9″. | Size, 2′ 8″ × 4′ 0″. | Size, 2′ 10″ × 4′ 3″. | Size, 3′ 0″ × 4′ 6″. | Size, 3′ 2″ × 4′ 9″. | Size, 3′ 4″ × 5′ 0″. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 in 100 | 378 | 556 | 778 | 1044 | 1356 | 1714 | 2127 | | | | | | | | |
| „ 110 | 361 | 530 | 741 | 995 | 1292 | 1637 | 2030 | | | | | | | | |
| „ 120 | 345 | 506 | 708 | 951 | 1238 | 1571 | 1948 | | | | | | | | |
| „ 130 | 331 | 488 | 682 | 915 | 1190 | 1509 | 1874 | | | | | | | | |
| „ 140 | 318 | 469 | 655 | 880 | 1145 | 1455 | 1805 | | | | | | | | |
| „ 150 | 307 | 452 | 633 | 850 | 1107 | 1405 | 1746 | | | | | | | | |
| „ 160 | 296 | 438 | 613 | 824 | 1072 | 1363 | 1691 | | | | | | | | |
| „ 170 | 287 | 424 | 594 | 798 | 1040 | 1320 | 1633 | | | | | | | | |
| „ 180 | 279 | 411 | 576 | 775 | 1011 | 1282 | 1588 | | | | | | | | |
| „ 190 | 271 | 400 | 562 | 755 | 982 | 1247 | 1553 | | | | | | | | |
| „ 200 | 264 | 389 | 546 | 734 | 957 | 1215 | 1511 | 1849 | 2226 | 2642 | 3103 | 3614 | 4165 | 4768 | 5423 |
| „ 250 | 235 | 347 | 486 | 654 | 852 | 1085 | 1351 | 1650 | 1988 | 2362 | 2777 | 3236 | 3731 | 4273 | 4862 |
| „ 300 | 213 | 316 | 442 | 595 | 775 | 988 | 1231 | 1504 | 1813 | 2153 | 2532 | 2950 | 3411 | 3904 | 4441 |
| „ 350 | 196 | 291 | 406 | 548 | 714 | 910 | 1135 | 1391 | 1676 | 1988 | 2336 | 2720 | 3142 | 3605 | 4096 |
| „ 400 | 183 | 270 | 380 | 512 | 667 | 849 | 1057 | 1294 | 1563 | 1859 | 2189 | 2545 | 2935 | 3363 | 3828 |
| „ 450 | 171 | 253 | 355 | 481 | 628 | 799 | 997 | 1219 | 1469 | 1751 | 2058 | 2397 | 2770 | 3179 | 3611 |
| „ 500 | 162 | 239 | 337 | 455 | 593 | 756 | 942 | 1154 | 1388 | 1651 | 1944 | 2268 | 2615 | 2994 | 3407 |
| „ 550 | 154 | 228 | 321 | 432 | 565 | 717 | 896 | 1094 | 1319 | 1572 | 1846 | 2148 | 2481 | 2845 | 3241 |
| „ 600 | 147 | 217 | 304 | 411 | 539 | 686 | 854 | 1046 | 1263 | 1500 | 1764 | 2056 | 2377 | 2729 | 3101 |
| „ 650 | 141 | 208 | 292 | 393 | 514 | 656 | 816 | 1003 | 1207 | 1436 | 1691 | 1973 | 2284 | 2614 | 2973 |
| „ 700 | 136 | 200 | 280 | 377 | 494 | 629 | 786 | 965 | 1163 | 1385 | 1633 | 1899 | 2191 | 2511 | 2858 |
| „ 750 | .. | 192 | 269 | 364 | 475 | 606 | 758 | 927 | 1119 | 1335 | 1576 | 1835 | 2119 | 2430 | 2756 |
| „ 800 | .. | 186 | 261 | 351 | 459 | 586 | 730 | 895 | 1082 | 1292 | 1519 | 1770 | 2047 | 2349 | 2667 |
| „ 850 | .. | .. | 253 | 341 | 447 | 567 | 707 | 868 | 1050 | 1249 | 1470 | 1715 | 1985 | 2269 | 2578 |
| „ 900 | .. | .. | 245 | 331 | 434 | 552 | 689 | 841 | 1013 | 1206 | 1421 | 1660 | 1923 | 2200 | 2501 |
| „ 950 | .. | .. | .. | 320 | 421 | 536 | 666 | 814 | 982 | 1170 | 1380 | 1613 | 1861 | 2131 | 2425 |
| „ 1000 | .. | .. | .. | 313 | 408 | 521 | 648 | 793 | 957 | 1141 | 1348 | 1567 | 1809 | 2073 | 2361 |
| „ 1100 | .. | .. | .. | .. | 386 | 494 | 615 | 755 | 913 | 1091 | 1282 | 1494 | 1726 | 1981 | 2259 |
| „ 1200 | .. | .. | .. | .. | .. | 471 | 588 | 722 | 875 | 1041 | 1225 | 1420 | 1643 | 1889 | 2144 |
| „ 1300 | .. | .. | .. | .. | .. | .. | 560 | 690 | 838 | 998 | 1168 | 1364 | 1571 | 1808 | 2055 |
| „ 1400 | .. | .. | .. | .. | .. | .. | .. | 663 | 800 | 955 | 1119 | 1309 | 1509 | 1739 | 1978 |
| „ 1500 | .. | .. | .. | .. | .. | .. | .. | 636 | 769 | 919 | 1086 | 1263 | 1457 | 1670 | 1901 |
| „ 1600 | .. | .. | .. | .. | .. | .. | .. | .. | 738 | 883 | 1045 | 1217 | 1406 | 1612 | 1838 |
| „ 1700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 854 | 1013 | 1180 | 1364 | 1566 | 1787 |
| „ 1800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 980 | 1143 | 1323 | 1520 | 1736 |
| „ 1900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 1106 | 1282 | 1474 | 1684 |
| „ 2000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 1251 | 1440 | 1633 |
| „ 2100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 1405 | 1595 |
| „ 2200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 1371 | 1557 |
| „ 2300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 1519 |
| „ 2400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2500 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2600 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3500 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3600 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |

**running full at VARIOUS RATES of INCLINATION.**

| Size, 3′ 8″ × 3′ 6″. | Size, 3′ 10″ × 5′ 9″. | Size, 4′ 0″ × 6′ 0″. | Size, 4′ 2″ × 6′ 3″. | Size, 4′ 4″ × 6′ 6″. | Size, 4′ 6″ × 6′ 9″. | Size, 4′ 8″ × 7′ 0″. | Size, 4′ 10″ × 7′ 3″. | Size, 5′ 0″ × 7′ 6″. | Size, 5′ 2″ × 7′ 9″. | Size, 5′ 4″ × 8′ 0″. | Size, 5′ 6″ × 8′ 3″. | Size, 5′ 8″ × 8′ 6″ | Size, 5′ 10″ × 8′ 9″. | Size, 6′ 0″ × 9′ 0″. | Inclination. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | 1 in 100 |
| | | | | | | | | | | | | | | | „ 110 |
| | | | | | | | | | | | | | | | „ 120 |
| | | | | | | | | | | | | | | | „ 130 |
| | | | | | | | | | | | | | | | „ 140 |
| | | | | | | | | | | | | | | | „ 150 |
| | | | | | | | | | | | | | | | „ 160 |
| | | | | | | | | | | | | | | | „ 170 |
| | | | | | | | | | | | | | | | „ 180 |
| | | | | | | | | | | | | | | | „ 190 |
| 6857 | 7662 | 8508 | 9411 | 10373 | 11396 | 12481 | 13630 | 14816 | 16068 | 17380 | 18761 | 20210 | 21729 | 23278 | „ 200 |
| 6149 | 6886 | 7644 | 8454 | 9317 | 10233 | 11205 | 12235 | 13323 | 14344 | 15648 | 16885 | 18182 | 19540 | 20962 | „ 250 |
| 5609 | 6278 | 6983 | 7736 | 8519 | 9373 | 10255 | 11188 | 12174 | 13217 | 14309 | 15460 | 16633 | 17860 | 19143 | „ 300 |
| 5193 | 5806 | 6468 | 7158 | 7893 | 8675 | 9504 | 10383 | 11284 | 12266 | 13263 | 14314 | 15416 | 16570 | 17779 | „ 350 |
| 4854 | 5434 | 6046 | 6700 | 7397 | 8140 | 8904 | 9713 | 10566 | 11469 | 12414 | 13410 | 14457 | 15554 | 16662 | „ 400 |
| 4577 | 5130 | 5715 | 6321 | 6966 | 7652 | 8379 | 9149 | 9963 | 10825 | 11695 | 12646 | 13609 | 14655 | 15711 | „ 450 |
| 4339 | 4860 | 5403 | 5982 | 6599 | 7256 | 7954 | 8693 | 9446 | 10273 | 11107 | 12021 | 12945 | 13913 | 14926 | „ 500 |
| 4114 | 4624 | 5145 | 5703 | 6297 | 6931 | 7578 | 8291 | 9016 | 9782 | 10585 | 11439 | 12318 | 13248 | 14223 | „ 550 |
| 3930 | 4405 | 4906 | 5443 | 6017 | 6605 | 7228 | 7915 | 8614 | 9353 | 10127 | 10944 | 11801 | 12701 | 13603 | „ 600 |
| 3775 | 4236 | 4723 | 5224 | 5758 | 6326 | 6928 | 7566 | 8240 | 8954 | 9703 | 10492 | 11322 | 12193 | 13065 | „ 650 |
| 3637 | 4084 | 4539 | 5025 | 5543 | 6093 | 6678 | 7298 | 7953 | 8648 | 9376 | 10110 | 10916 | 11724 | 12569 | „ 700 |
| 3513 | 3932 | 4373 | 4845 | 5348 | 5884 | 6453 | 7056 | 7695 | 8341 | 9049 | 9763 | 10548 | 11333 | 12155 | „ 750 |
| 3390 | 3797 | 4226 | 4686 | 5176 | 5698 | 6253 | 6842 | 7437 | 8065 | 8755 | 9450 | 10179 | 10943 | 11742 | „ 800 |
| 3282 | 3679 | 4098 | 4546 | 5025 | 5512 | 6053 | 6627 | 7207 | 7820 | 8461 | 9137 | 9847 | 10591 | 11360 | „ 850 |
| 3174 | 3561 | 3969 | 4407 | 4874 | 5349 | 5878 | 6412 | 6977 | 7574 | 8200 | 8859 | 9552 | 10278 | 11039 | „ 900 |
| 3082 | 3460 | 3859 | 4287 | 4723 | 5186 | 5703 | 6225 | 6776 | 7360 | 7971 | 8616 | 9294 | 10005 | 10750 | „ 950 |
| 3005 | 3375 | 3767 | 4167 | 4594 | 5047 | 5553 | 6064 | 6604 | 7176 | 7775 | 8408 | 9072 | 9770 | 10461 | „ 1000 |
| 2866 | 3223 | 3583 | 3968 | 4378 | 4814 | 5277 | 5768 | 6288 | 6838 | 7416 | 7991 | 8630 | 9301 | 9964 | „ 1100 |
| 2743 | 3072 | 3418 | 3788 | 4184 | 4605 | 5052 | 5527 | 6001 | 6532 | 7056 | 7609 | 8224 | 8871 | 9510 | „ 1200 |
| 2620 | 2936 | 3271 | 3629 | 4011 | 4419 | 4827 | 5286 | 5743 | 6256 | 6762 | 7296 | 7892 | 8481 | 9096 | „ 1300 |
| 2512 | 2818 | 3142 | 3489 | 3839 | 4233 | 4627 | 5071 | 5513 | 6010 | 6501 | 7018 | 7597 | 8168 | 8765 | „ 1400 |
| 2419 | 2717 | 3032 | 3370 | 3709 | 4093 | 4477 | 4910 | 5341 | 5796 | 6272 | 6775 | 7302 | 7855 | 8435 | „ 1500 |
| 2342 | 2633 | 2922 | 3250 | 3580 | 3954 | 4327 | 4749 | 5168 | 5612 | 6076 | 6566 | 7081 | 7621 | 8186 | „ 1600 |
| 2265 | 2548 | 2830 | 3150 | 3472 | 3814 | 4177 | 4588 | 4996 | 5428 | 5880 | 6358 | 6860 | 7386 | 7938 | „ 1700 |
| 2188 | 2464 | 2738 | 3051 | 3364 | 3698 | 4052 | 4454 | 4852 | 5274 | 5717 | 6149 | 6638 | 7152 | 7690 | „ 1800 |
| 2127 | 2396 | 2665 | 2951 | 3257 | 3582 | 3927 | 4320 | 4709 | 5121 | 5554 | 5976 | 6454 | 6956 | 7484 | „ 1900 |
| 2065 | 2329 | 2591 | 2871 | 3170 | 3489 | 3827 | 4186 | 4565 | 4968 | 5390 | 5802 | 6270 | 6761 | 7277 | „ 2000 |
| 2019 | 2261 | 2518 | 2791 | 3084 | 3395 | 3727 | 4078 | 4450 | 4845 | 5260 | 5663 | 6122 | 6605 | 7070 | „ 2100 |
| 1972 | 2211 | 2462 | 2732 | 3019 | 3326 | 3652 | 3998 | 4336 | 4722 | 5129 | 5524 | 5974 | 6448 | 6905 | „ 2200 |
| 1926 | 2160 | 2407 | 2672 | 2955 | 3256 | 3552 | 3890 | 4249 | 4600 | 4998 | 5385 | 5827 | 6292 | 6739 | „ 2300 |
| 1880 | 2110 | 2352 | 2612 | 2890 | 3186 | 3477 | 3810 | 4163 | 4508 | 4900 | 5281 | 5716 | 6136 | 6574 | „ 2400 |
| 1834 | 2059 | 2297 | 2552 | 2825 | 3116 | 3402 | 3729 | 4048 | 4416 | 4802 | 5177 | 5569 | 6018 | 6450 | „ 2500 |
| .. | 2025 | 2242 | 2492 | 2760 | 3047 | 3327 | 3649 | 3962 | 4324 | 4672 | 5072 | 5458 | 5901 | 6326 | „ 2600 |
| .. | .. | 2205 | 2433 | 2696 | 2977 | 3252 | 3568 | 3876 | 4232 | 4574 | 4968 | 5348 | 5745 | 6202 | „ 2700 |
| .. | .. | .. | 2393 | 2653 | 2907 | 3201 | 3488 | 3819 | 4110 | 4508 | 4864 | 5237 | 5628 | 6078 | „ 2800 |
| .. | .. | .. | .. | 2588 | 2861 | 3126 | 3434 | 3733 | 4078 | 4410 | 4760 | 5126 | 5549 | 5954 | „ 2900 |
| .. | .. | .. | .. | .. | 2814 | 3076 | 3381 | 3675 | 3986 | 4345 | 4690 | 5052 | 5432 | 5830 | „ 3000 |
| .. | .. | .. | .. | .. | 2744 | 3001 | 3300 | 3618 | 3925 | 4247 | 4586 | 4942 | 5354 | 5747 | „ 3100 |
| .. | .. | .. | .. | .. | .. | 2951 | 3246 | 3532 | 3864 | 4182 | 4516 | 4868 | 5237 | 5623 | „ 3200 |
| .. | .. | .. | .. | .. | .. | .. | 3193 | 3474 | 3802 | 4116 | 4447 | 4794 | 5159 | 5540 | „ 3300 |
| .. | .. | .. | .. | .. | .. | .. | .. | 3417 | 3741 | 4051 | 4377 | 4721 | 5081 | 5458 | „ 3400 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | 3680 | 3986 | 4308 | 4647 | 5002 | 5375 | „ 3500 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 3920 | 4239 | 4573 | 4924 | 5292 | „ 3600 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 4169 | 4499 | 4846 | 5210 | „ 3700 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 4426 | 4768 | 5127 | „ 3800 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 4690 | 5044 | „ 3900 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 4962 | „ 4000 |

TABLE 23.—DISCHARGE in cube feet per minute for EGG-SHAPED SEWER

| Inclination. | Size, 1′ 0″ × 1′ 6″. | Size, 1′ 2″ × 1′ 9″. | Size, 1′ 4″ × 2′ 0″. | Size, 1′ 6″ × 2′ 3′. | Size, 1′ 8″ × 2′ 6″. | Size, 1′ 10″ × 2′ 9″. | Size, 2′ 0″ × 3′ 0″. | Size, 2′ 2″ × 3′ 3″. | Size, 2′ 4″ × 3′ 6″. | Size, 2′ 6″ × 3′ 9″. | Size, 2′ 8″ × 4′ 0″. | Size, 2′ 10″ × 4′ 3″. | Size, 3′ 0″ × 4′ 6″. | Size, 3′ 2″ × 4′ 9″. | Size, 3′ 4″ × 5′ 0″. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 In 100 | 260 | 382 | 531 | 714 | 926 | 1173 | 1460 | | | | | | | | |
| „ 110 | 248 | 364 | 507 | 682 | 884 | 1120 | 1397 | | | | | | | | |
| „ 120 | 237 | 349 | 486 | 653 | 848 | 1074 | 1336 | | | | | | | | |
| „ 130 | 227 | 335 | 467 | 627 | 815 | 1034 | 1285 | | | | | | | | |
| „ 140 | 219 | 323 | 451 | 605 | 785 | 996 | 1239 | | | | | | | | |
| „ 150 | 212 | 312 | 435 | 585 | 760 | 963 | 1197 | | | | | | | | |
| „ 160 | 205 | 302 | 422 | 566 | 737 | 935 | 1161 | | | | | | | | |
| „ 170 | 198 | 292 | 408 | 549 | 714 | 907 | 1128 | | | | | | | | |
| „ 180 | 192 | 283 | 396 | 534 | 693 | 881 | 1087 | | | | | | | | |
| „ 190 | 187 | 276 | 385 | 519 | 674 | 856 | 1057 | | | | | | | | |
| „ 200 | 182 | 269 | 376 | 506 | 659 | 836 | 1040 | 1270 | 1527 | 1814 | 2128 | 2475 | 2857 | 3267 | 3712 |
| „ 250 | 162 | 239 | 334 | 451 | 588 | 747 | 928 | 1135 | 1366 | 1625 | 1908 | 2221 | 2564 | 2933 | 3334 |
| „ 300 | 147 | 217 | 303 | 410 | 536 | 681 | 846 | 1036 | 1247 | 1483 | 1741 | 2027 | 2340 | 2675 | 3040 |
| „ 350 | 135 | 200 | 279 | 378 | 494 | 627 | 780 | 954 | 1152 | 1370 | 1612 | 1875 | 2163 | 2478 | 2822 |
| „ 400 | 126 | 186 | 260 | 352 | 460 | 584 | 729 | 891 | 1074 | 1280 | 1505 | 1753 | 2020 | 2312 | 2629 |
| „ 450 | 119 | 175 | 245 | 332 | 433 | 549 | 683 | 837 | 1008 | 1200 | 1414 | 1650 | 1905 | 2183 | 2486 |
| „ 500 | 112 | 166 | 232 | 313 | 410 | 521 | 647 | 791 | 955 | 1138 | 1338 | 1559 | 1803 | 2069 | 2351 |
| „ 550 | 107 | 157 | 220 | 298 | 389 | 496 | 617 | 752 | 909 | 1082 | 1274 | 1487 | 1714 | 1963 | 2234 |
| „ 600 | 101 | 150 | 210 | 284 | 370 | 473 | 590 | 720 | 868 | 1034 | 1215 | 1414 | 1633 | 1872 | 2133 |
| „ 650 | 97 | 143 | 201 | 272 | 355 | 452 | 565 | 692 | 835 | 992 | 1166 | 1359 | 1571 | 1796 | 2041 |
| „ 700 | 93 | 138 | 193 | 260 | 340 | 434 | 541 | 663 | 802 | 954 | 1123 | 1310 | 1510 | 1728 | 1965 |
| „ 750 | 90 | 133 | 186 | 251 | 328 | 419 | 523 | 642 | 774 | 921 | 1080 | 1262 | 1456 | 1667 | 1898 |
| „ 800 | .. | 129 | 180 | 243 | 317 | 404 | 505 | 621 | 749 | 888 | 1043 | 1220 | 1408 | 1614 | 1839 |
| „ 850 | .. | 124 | 174 | 235 | 306 | 391 | 490 | 600 | 724 | 860 | 1010 | 1177 | 1360 | 1561 | 1780 |
| „ 900 | .. | .. | 169 | 228 | 298 | 378 | 475 | 582 | 700 | 831 | 978 | 1141 | 1320 | 1516 | 1730 |
| „ 950 | .. | .. | 164 | 221 | 290 | 368 | 460 | 564 | 679 | 808 | 951 | 1110 | 1286 | 1470 | 1680 |
| „ 1000 | .. | .. | 160 | 216 | 281 | 358 | 447 | 550 | 662 | 789 | 930 | 1086 | 1252 | 1432 | 1638 |
| „ 1100 | .. | .. | .. | 204 | 266 | 340 | 426 | 522 | 630 | 751 | 881 | 1031 | 1190 | 1364 | 1554 |
| „ 1200 | .. | .. | .. | .. | 256 | 325 | 405 | 497 | 601 | 718 | 844 | 983 | 1140 | 1304 | 1486 |
| „ 1300 | .. | .. | .. | .. | .. | 312 | 390 | 475 | 576 | 685 | 806 | 940 | 1088 | 1251 | 1419 |
| „ 1400 | .. | .. | .. | .. | .. | 302 | 375 | 458 | 551 | 657 | 774 | 904 | 1041 | 1197 | 1360 |
| „ 1500 | .. | .. | .. | .. | .. | .. | 363 | 440 | 531 | 633 | 747 | 874 | 1007 | 1160 | 1318 |
| „ 1600 | .. | .. | .. | .. | .. | .. | .. | 426 | 510 | 609 | 720 | 843 | 973 | 1114 | 1268 |
| „ 1700 | .. | .. | .. | .. | .. | .. | .. | .. | 494 | 590 | 693 | 813 | 939 | 1076 | 1226 |
| „ 1800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 572 | 672 | 789 | 911 | 1046 | 1192 |
| „ 1900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 656 | 764 | 844 | 1016 | 1159 |
| „ 2000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 640 | 746 | 857 | 985 | 1125 |
| „ 2100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 728 | 837 | 963 | 1092 |
| „ 2200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 816 | 940 | 1067 |
| „ 2300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 917 | 1041 |
| „ 2400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 1016 |
| „ 2500 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 1000 |
| „ 2600 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3500 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3600 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 3900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 4400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |

**hen running two-thirds full at VARIOUS RATES of INCLINATION.**

| Size, 3' 6" × 3' 3". | Size, 3' 8" × 5' 6". | Size, 3' 10" × 5' 9". | Size, 4' 0" × 6' 0". | Size, 4' 2" × 6' 3". | Size, 4' 4" × 6' 6". | Size, 4' 6" × 6' 9". | Size, 4' 8" × 7' 0". | Size, 4' 10" × 7' 3". | Size, 5' 0" × 7' 6". | Size, 5' 2" × 7' 9". | Size, 5' 4" × 8' 0". | Size, 5' 6" × 8' 3". | Size, 5' 8" × 8' 6". | Size, 5' 10" × 8' 9". | Size, 6' 0" × 9' 0". | Inclination. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | 1 in 100 |
| | | | | | | | | | | | | | | | | „ 110 |
| | | | | | | | | | | | | | | | | „ 120 |
| | | | | | | | | | | | | | | | | „ 130 |
| | | | | | | | | | | | | | | | | „ 140 |
| | | | | | | | | | | | | | | | | „ 150 |
| | | | | | | | | | | | | | | | | „ 160 |
| | | | | | | | | | | | | | | | | „ 170 |
| | | | | | | | | | | | | | | | | „ 180 |
| | | | | | | | | | | | | | | | | „ 190 |
| 1194 | 4705 | 5253 | 5841 | 6469 | 7139 | 7836 | 8575 | 9358 | 10166 | 11016 | 11910 | 12849 | 13834 | 14865 | 15917 | „ 200 |
| 1768 | 4227 | 4720 | 5248 | 5813 | 6415 | 7040 | 7703 | 8404 | 9145 | 9906 | 10706 | 11569 | 12450 | 13373 | 14339 | „ 250 |
| 1455 | 3862 | 4320 | 4801 | 5314 | 5861 | 6443 | 7045 | 7680 | 8352 | 9059 | 9803 | 10586 | 11407 | 12268 | 13142 | „ 300 |
| 1185 | 3577 | 3998 | 4450 | 4934 | 5436 | 5969 | 6534 | 7133 | 7766 | 8413 | 9094 | 9808 | 10582 | 11367 | 12190 | „ 350 |
| 972 | 3343 | 3743 | 4160 | 4606 | 5081 | 5586 | 6123 | 6674 | 7256 | 7869 | 8513 | 9191 | 9902 | 10647 | 11428 | „ 400 |
| 805 | 3150 | 3521 | 3918 | 4343 | 4797 | 5280 | 5777 | 6303 | 6859 | 7445 | 8040 | 8688 | 9344 | 10056 | 10775 | „ 450 |
| 857 | 2987 | 3332 | 3712 | 4120 | 4556 | 5005 | 5481 | 5985 | 6500 | 7061 | 7632 | 8254 | 8883 | 9541 | 10231 | „ 500 |
| 829 | 2845 | 3176 | 3543 | 3923 | 4329 | 4760 | 5218 | 5703 | 6198 | 6719 | 7266 | 7865 | 8470 | 9104 | 9768 | „ 550 |
| 816 | 2723 | 3043 | 3386 | 3753 | 4144 | 4561 | 5004 | 5456 | 5933 | 6436 | 6965 | 7522 | 8106 | 8718 | 9360 | „ 600 |
| 315 | 2601 | 2910 | 3241 | 3595 | 3974 | 4377 | 4806 | 5244 | 5706 | 6194 | 6707 | 7225 | 7791 | 8384 | 9006 | „ 650 |
| 222 | 2500 | 2799 | 3120 | 3464 | 3832 | 4209 | 4609 | 5032 | 5480 | 5952 | 6449 | 6950 | 7499 | 8050 | 8652 | „ 700 |
| 048 | 2418 | 2699 | 3011 | 3346 | 3690 | 4056 | 4444 | 4855 | 5272 | 5730 | 6213 | 6699 | 7232 | 7767 | 8353 | „ 750 |
| 974 | 2337 | 2610 | 2914 | 3228 | 3562 | 3918 | 4296 | 4697 | 5102 | 5548 | 6020 | 6493 | 7014 | 7535 | 8081 | „ 800 |
| 909 | 2266 | 2532 | 2818 | 3123 | 3449 | 3796 | 4164 | 4555 | 4950 | 5387 | 5826 | 6287 | 6795 | 7304 | 7836 | „ 850 |
| 854 | 2195 | 2454 | 2733 | 3031 | 3349 | 3688 | 4049 | 4414 | 4799 | 5226 | 5654 | 6104 | 6601 | 7098 | 7618 | „ 900 |
| 809 | 2134 | 2388 | 2660 | 2952 | 3264 | 3581 | 3934 | 4290 | 4667 | 5084 | 5504 | 5944 | 6407 | 6892 | 7401 | „ 950 |
| 852 | 2083 | 2332 | 2588 | 2874 | 3179 | 3490 | 3819 | 4167 | 4535 | 4943 | 5353 | 5784 | 6237 | 6712 | 7210 | „ 1000 |
| 739 | 1981 | 2210 | 2455 | 2729 | 3023 | 3321 | 3638 | 3973 | 4327 | 4701 | 5095 | 5510 | 5922 | 6378 | 6857 | „ 1100 |
| 676 | 1890 | 2110 | 2346 | 2611 | 2881 | 3168 | 3473 | 3796 | 4138 | 4479 | 4859 | 5258 | 5655 | 6095 | 6530 | „ 1200 |
| 602 | 1809 | 2021 | 2249 | 2506 | 2767 | 3046 | 3325 | 3637 | 3967 | 4297 | 4644 | 5030 | 5412 | 5838 | 6258 | „ 1300 |
| 546 | 1738 | 1944 | 2165 | 2401 | 2654 | 2923 | 3193 | 3496 | 3817 | 4136 | 4472 | 4847 | 5218 | 5632 | 6040 | „ 1400 |
| 491 | 1677 | 1877 | 2092 | 2323 | 2568 | 2831 | 3094 | 3372 | 3685 | 3995 | 4321 | 4687 | 5048 | 5427 | 5823 | „ 1500 |
| 435 | 1616 | 1810 | 2019 | 2244 | 2484 | 2724 | 2996 | 3266 | 3552 | 3854 | 4171 | 4527 | 4878 | 5247 | 5632 | „ 1600 |
| 389 | 1565 | 1755 | 1959 | 2165 | 2398 | 2632 | 2897 | 3160 | 3439 | 3733 | 4042 | 4367 | 4708 | 5066 | 5442 | „ 1700 |
| 352 | 1514 | 1699 | 1899 | 2099 | 2328 | 2556 | 2815 | 3072 | 3344 | 3611 | 3913 | 4252 | 4587 | 4912 | 5279 | „ 1800 |
| 315 | 1473 | 1655 | 1838 | 2047 | 2257 | 2479 | 2732 | 2984 | 3250 | 3511 | 3805 | 4115 | 4441 | 4784 | 5142 | „ 1900 |
| 278 | 1433 | 1610 | 1790 | 1994 | 2200 | 2418 | 2650 | 2896 | 3155 | 3430 | 3719 | 4024 | 4320 | 4655 | 5006 | „ 2000 |
| 241 | 1392 | 1566 | 1741 | 1942 | 2143 | 2357 | 2584 | 2825 | 3080 | 3349 | 3612 | 3910 | 4223 | 4526 | 4870 | „ 2100 |
| 213 | 1362 | 1522 | 1693 | 1889 | 2086 | 2296 | 2518 | 2754 | 3004 | 3268 | 3526 | 3818 | 4126 | 4424 | 4762 | „ 2200 |
| 185 | 1331 | 1488 | 1657 | 1837 | 2029 | 2235 | 2452 | 2684 | 2929 | 3188 | 3440 | 3727 | 4029 | 4321 | 4653 | „ 2300 |
| 157 | 1301 | 1455 | 1620 | 1798 | 1987 | 2189 | 2403 | 2613 | 2853 | 3107 | 3354 | 3635 | 3932 | 4218 | 4544 | „ 2400 |
| 139 | 1270 | 1422 | 1584 | 1758 | 1944 | 2143 | 2354 | 2560 | 2778 | 3026 | 3289 | 3567 | 3835 | 4115 | 4435 | „ 2500 |
| 111 | 1240 | 1388 | 1548 | 1719 | 1902 | 2097 | 2304 | 2507 | 2721 | 2966 | 3225 | 3498 | 3762 | 4038 | 4326 | „ 2600 |
| .. | 1219 | 1366 | 1524 | 1693 | 1873 | 2051 | 2255 | 2454 | 2664 | 2905 | 3160 | 3429 | 3689 | 3961 | 4245 | „ 2700 |
| .. | .. | 1344 | 1500 | 1653 | 1831 | 2020 | 2206 | 2401 | 2626 | 2865 | 3096 | 3361 | 3616 | 3883 | 4163 | „ 2800 |
| .. | .. | .. | 1463 | 1627 | 1788 | 1974 | 2156 | 2366 | 2570 | 2804 | 3031 | 3292 | 3543 | 3806 | 4081 | „ 2900 |
| .. | .. | .. | 1439 | 1601 | 1760 | 1944 | 2123 | 2331 | 2532 | 2744 | 2988 | 3224 | 3495 | 3755 | 4027 | „ 3000 |
| .. | .. | .. | .. | 1575 | 1731 | 1913 | 2090 | 2278 | 2475 | 2704 | 2924 | 3155 | 3422 | 3678 | 3945 | „ 3100 |
| .. | .. | .. | .. | .. | 1703 | 1883 | 2057 | 2242 | 2437 | 2663 | 2881 | 3109 | 3373 | 3626 | 3891 | „ 3200 |
| .. | .. | .. | .. | .. | .. | 1852 | 2025 | 2207 | 2400 | 2623 | 2838 | 3064 | 3325 | 3575 | 3836 | „ 3300 |
| .. | .. | .. | .. | .. | .. | 1821 | 1992 | 2172 | 2362 | 2582 | 2795 | 3018 | 3252 | 3498 | 3755 | „ 3400 |
| .. | .. | .. | .. | .. | .. | .. | 1959 | 2136 | 2324 | 2542 | 2752 | 2972 | 3204 | 3446 | 3700 | „ 3500 |
| .. | .. | .. | .. | .. | .. | .. | .. | 2101 | 2286 | 2502 | 2709 | 2926 | 3155 | 3395 | 3646 | „ 3600 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | 2267 | 2461 | 2666 | 2881 | 3107 | 3343 | 3592 | „ 3700 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 2421 | 2623 | 2835 | 3058 | 3292 | 3537 | „ 3800 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 2580 | 2789 | 3009 | 3240 | 3483 | „ 3900 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 2766 | 2961 | 3189 | 3428 | „ 4000 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 2721 | 2937 | 3163 | 3401 | „ 4100 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 2888 | 3112 | 3347 | „ 4200 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 3086 | 3319 | „ 4300 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 3265 | „ 4400 |

TABLE No. 24.—DISCHARGE in cube feet per minute for EGG-SHAPED SEWER

| Inclination. | Size, 1′ 0″ × 1′ 6″. | Size, 1′ 2″ × 1′ 9″. | Size, 1′ 4″ × 2′ 0″. | Size, 1′ 6″ × 2′ 3″. | Size, 1′ 8″ × 2′ 6″. | Size, 1′ 10″ × 2′ 9″. | Size, 2′ 0″ × 3′ 0″. | Size, 2′ 2″ × 3′ 3″. | Size, 2′ 4″ × 3′ 6″. | Size, 2′ 6″ × 3′ 9″. | Size, 2′ 8″ × 4′ 0″. | Size, 2′ 10″ × 4′ 3″. | Size, 3′ 0″ × 4′ 6″. | Size, 3′ 2″ × 4′ 9″. | Size, 3′ 4″ × 5′ 0″. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 in 100 | 78·5 | 116 | 162 | 218 | 283 | 360 | 448 | | | | | | | | |
| „ 110 | 74·9 | 110 | 154 | 208 | 270 | 343 | 427 | | | | | | | | |
| „ 120 | 71·5 | 105 | 147 | 199 | 259 | 328 | 409 | | | | | | | | |
| „ 130 | 68·4 | 101 | 141 | 190 | 248 | 315 | 392 | | | | | | | | |
| „ 140 | 65·9 | 97·3 | 136 | 183 | 239 | 304 | 378 | | | | | | | | |
| „ 150 | 63·6 | 93·8 | 131 | 177 | 230 | 293 | 365 | | | | | | | | |
| „ 160 | 61·6 | 90·7 | 127 | 171 | 223 | 283 | 353 | | | | | | | | |
| „ 170 | 59·6 | 87·6 | 123 | 166 | 216 | 275 | 343 | | | | | | | | |
| „ 180 | 57·9 | 85·3 | 120 | 161 | 210 | 267 | 333 | | | | | | | | |
| „ 190 | 56·3 | 83·0 | 116 | 156 | 204 | 260 | 324 | | | | | | | | |
| „ 200 | 54·8 | 80·7 | 113 | 152 | 198 | 252 | 315 | 385 | 464 | 552 | 648 | 755 | 872 | 997 | 1133 |
| „ 250 | 48·6 | 71·8 | 100 | 135 | 177 | 225 | 281 | 343 | 413 | 492 | 578 | 673 | 777 | 891 | 1013 |
| „ 300 | 44·0 | 65·2 | 91·3 | 123 | 161 | 204 | 254 | 312 | 376 | 448 | 527 | 613 | 708 | 812 | 925 |
| „ 350 | 40·6 | 59·8 | 83·7 | 113 | 148 | 188 | 235 | 288 | 347 | 412 | 485 | 566 | 654 | 749 | 852 |
| „ 400 | 37·7 | 55·6 | 78·2 | 105 | 138 | 176 | 219 | 268 | 323 | 384 | 453 | 527 | 609 | 698 | 795 |
| „ 450 | 35·5 | 52·1 | 73·1 | 99·0 | 129 | 165 | 205 | 252 | 303 | 361 | 425 | 495 | 573 | 655 | 748 |
| „ 500 | 33·5 | 49·4 | 69·1 | 93·2 | 122 | 156 | 194 | 238 | 288 | 343 | 402 | 470 | 542 | 621 | 707 |
| „ 550 | .. | 47·1 | 65·6 | 88·7 | 116 | 148 | 184 | 226 | 274 | 327 | 384 | 447 | 516 | 592 | 672 |
| „ 600 | .. | .. | 63·0 | 84·9 | 110 | 141 | 176 | 216 | 261 | 311 | 366 | 427 | 493 | 567 | 644 |
| „ 650 | .. | .. | 60·0 | 81·0 | 106 | 135 | 168 | 206 | 249 | 297 | 350 | 408 | 473 | 541 | 615 |
| „ 700 | .. | .. | .. | 77·8 | 102 | 130 | 162 | 198 | 239 | 286 | 337 | 392 | 452 | 518 | 590 |
| „ 750 | .. | .. | .. | 75·3 | 97·8 | 125 | 157 | 192 | 230 | 275 | 325 | 378 | 437 | 501 | 571 |
| „ 800 | .. | .. | .. | .. | 94·7 | 121 | 151 | 185 | 222 | 266 | 313 | 365 | 422 | 484 | 552 |
| „ 850 | .. | .. | .. | .. | .. | 117 | 146 | 180 | 216 | 257 | 303 | 353 | 409 | 470 | 533 |
| „ 900 | .. | .. | .. | .. | .. | 114 | 142 | 174 | 210 | 250 | 293 | 342 | 396 | 456 | 518 |
| „ 950 | .. | .. | .. | .. | .. | .. | 137 | 169 | 204 | 243 | 285 | 333 | 386 | 441 | 502 |
| „ 1000 | .. | .. | .. | .. | .. | .. | .. | 164 | 198 | 236 | 277 | 324 | 373 | 427 | 489 |
| „ 1100 | .. | .. | .. | .. | .. | .. | .. | .. | 187 | 223 | 262 | 308 | 355 | 407 | 464 |
| „ 1200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 213 | 250 | 294 | 340 | 390 | 445 |
| „ 1300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 240 | 280 | 324 | 373 | 426 |
| „ 1400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 269 | 312 | 359 | 410 |
| „ 1500 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 302 | 347 | 384 |
| „ 1600 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 336 | 379 |
| „ 1700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 1800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 1900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2000 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2200 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2300 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2400 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2500 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2600 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2800 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| „ 2900 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |

hen running one-third full at VARIOUS RATES of INCLINATION.

| Size, 2′ 8″ × 5′ 6″. | Size, 3′ 10″ × 5′ 9″. | Size, 4′ 0″ × 6′ 0″. | Size, 4′ 2″ × 6′ 3″. | Size, 4′ 4″ × 6′ 6″. | Size, 4′ 6″ × 6′ 9″. | Size, 4′ 8″ × 7′ 0″. | Size, 4′ 10″ × 7′ 3″. | Size, 5′ 0″ × 7′ 6″. | Size, 5′ 2″ × 7′ 9″. | Size, 5′ 4″ × 8′ 0″. | Size, 5′ 6″ × 8′ 3″. | Size, 5′ 8″ × 8′ 6″. | Size, 5′ 10″ × 8′ 9″. | Size, 6′ 0″ × 9′ 0″. | Inclination. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | 1 in 100 |
| | | | | | | | | | | | | | | | „ 110 |
| | | | | | | | | | | | | | | | „ 120 |
| | | | | | | | | | | | | | | | „ 130 |
| | | | | | | | | | | | | | | | „ 140 |
| | | | | | | | | | | | | | | | „ 150 |
| | | | | | | | | | | | | | | | „ 160 |
| | | | | | | | | | | | | | | | „ 170 |
| | | | | | | | | | | | | | | | „ 180 |
| | | | | | | | | | | | | | | | „ 190 |
| 1439 | 1607 | 1786 | 1977 | 2181 | 2398 | 2622 | 2860 | 3110 | 3374 | 3651 | 3943 | 4250 | 4571 | 4897 | „ 200 |
| 1287 | 1440 | 1599 | 1770 | 1952 | 2145 | 2350 | 2568 | 2790 | 3025 | 3280 | 3539 | 3812 | 4097 | 4396 | „ 250 |
| 1172 | 1310 | 1459 | 1617 | 1781 | 1961 | 2146 | 2342 | 2549 | 2767 | 2997 | 3239 | 3484 | 3750 | 4018 | „ 300 |
| 1084 | 1214 | 1350 | 1494 | 1648 | 1812 | 1985 | 2163 | 2357 | 2562 | 2771 | 2998 | 3228 | 3469 | 3722 | „ 350 |
| 1012 | 1131 | 1259 | 1395 | 1541 | 1691 | 1855 | 2024 | 2208 | 2396 | 2593 | 2801 | 3019 | 3247 | 3486 | „ 400 |
| 951 | 1064 | 1186 | 1312 | 1451 | 1593 | 1744 | 1904 | 2080 | 2259 | 2448 | 2637 | 2845 | 3054 | 3282 | „ 450 |
| 901 | 1010 | 1122 | 1243 | 1371 | 1507 | 1651 | 1805 | 1967 | 2138 | 2318 | 2500 | 2699 | 2899 | 3108 | „ 500 |
| 855 | 960 | 1068 | 1183 | 1307 | 1432 | 1571 | 1718 | 1874 | 2039 | 2205 | 2380 | 2572 | 2764 | 2965 | „ 550 |
| 817 | 914 | 1018 | 1129 | 1248 | 1369 | 1503 | 1645 | 1789 | 1948 | 2108 | 2277 | 2453 | 2638 | 2832 | „ 600 |
| 783 | 876 | 977 | 1085 | 1195 | 1311 | 1441 | 1579 | 1718 | 1865 | 2020 | 2182 | 2353 | 2532 | 2720 | „ 650 |
| 752 | 843 | 941 | 1045 | 1152 | 1265 | 1385 | 1513 | 1647 | 1789 | 1939 | 2096 | 2262 | 2435 | 2617 | „ 700 |
| 725 | 814 | 904 | 1006 | 1109 | 1219 | 1336 | 1460 | 1590 | 1729 | 1874 | 2027 | 2189 | 2358 | 2525 | „ 750 |
| 703 | 785 | 872 | 971 | 1072 | 1179 | 1293 | 1413 | 1541 | 1675 | 1818 | 1959 | 2116 | 2271 | 2433 | „ 800 |
| 680 | 760 | 845 | 942 | 1040 | 1144 | 1256 | 1367 | 1491 | 1622 | 1761 | 1899 | 2052 | 2203 | 2362 | „ 850 |
| 657 | 734 | 818 | 912 | 1008 | 1110 | 1218 | 1327 | 1448 | 1577 | 1705 | 1838 | 1988 | 2136 | 2290 | „ 900 |
| 638 | 714 | 795 | 883 | 976 | 1075 | 1181 | 1287 | 1406 | 1531 | 1656 | 1787 | 1933 | 2078 | 2229 | „ 950 |
| 622 | 697 | 777 | 863 | 955 | 1047 | 1150 | 1254 | 1370 | 1493 | 1616 | 1744 | 1879 | 2020 | 2167 | „ 1000 |
| 592 | 664 | 736 | 818 | 907 | 995 | 1095 | 1194 | 1299 | 1418 | 1535 | 1658 | 1787 | 1923 | 2065 | „ 1100 |
| 565 | 634 | 704 | 784 | 864 | 949 | 1045 | 1141 | 1242 | 1349 | 1462 | 1581 | 1705 | 1836 | 1973 | „ 1200 |
| 542 | 609 | 677 | 749 | 827 | 909 | 996 | 1088 | 1186 | 1289 | 1398 | 1512 | 1632 | 1759 | 1891 | „ 1300 |
| 519 | 584 | 650 | 720 | 795 | 874 | 959 | 1048 | 1143 | 1243 | 1349 | 1452 | 1569 | 1691 | 1810 | „ 1400 |
| 500 | 559 | 623 | 690 | 763 | 840 | 922 | 1008 | 1100 | 1198 | 1301 | 1400 | 1514 | 1633 | 1748 | „ 1500 |
| 481 | 538 | 600 | 666 | 736 | 811 | 891 | 975 | 1065 | 1160 | 1252 | 1349 | 1459 | 1575 | 1687 | „ 1600 |
| 466 | 522 | 582 | 646 | 715 | 788 | 866 | 942 | 1029 | 1122 | 1212 | 1306 | 1414 | 1527 | 1636 | „ 1700 |
| 454 | 509 | 563 | 626 | 693 | 765 | 841 | 916 | 994 | 1084 | 1171 | 1271 | 1368 | 1479 | 1585 | „ 1800 |
| .. | 496 | 550 | 611 | 672 | 742 | 816 | 889 | 966 | 1054 | 1139 | 1237 | 1331 | 1430 | 1534 | „ 1900 |
| .. | .. | 536 | 597 | 656 | 719 | 792 | 862 | 944 | 1023 | 1115 | 1203 | 1295 | 1392 | 1493 | „ 2000 |
| .. | .. | .. | .. | 646 | 702 | 773 | 843 | 916 | 1001 | 1082 | 1168 | 1259 | 1353 | 1452 | „ 2100 |
| .. | .. | .. | .. | .. | 684 | 755 | 823 | 895 | 978 | 1058 | 1143 | 1231 | 1324 | 1421 | „ 2200 |
| .. | .. | .. | .. | .. | .. | 736 | 803 | 873 | 948 | 1026 | 1108 | 1204 | 1295 | 1390 | „ 2300 |
| .. | .. | .. | .. | .. | .. | .. | .. | 852 | 925 | 1002 | 1082 | 1176 | 1266 | 1360 | „ 2400 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | 902 | 977 | 1057 | 1149 | 1237 | 1329 | „ 2500 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 961 | 1040 | 1122 | 1208 | 1298 | „ 2600 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 1022 | 1103 | 1189 | 1268 | „ 2700 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 1085 | 1160 | 1247 | „ 2800 |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 1227 | „ 2900 |

## COURSE OF SEWERS.

Natural and artificial drainage.

When the natural drainage area of the district has been defined, it will be well to ascertain what nature has done for the drainage, and also what has already been done by art in the way of accomplishing the work of sewerage of the district. The main lines of

Direction of main lines of sewers.

sewers will generally take the direction of the natural drainage valleys. Such drainage valleys will also give the lines in which the storm-water overflows will have to be constructed. The subsidiary sewers of the district

Sewers to be laid in straight lines.

are now usually laid in perfectly straight lines, having manholes at every point of lateral deviation; and manholes, lampholes, or ventilators at every vertical deviation or change of gradient. By constructing a system of sewers in straight lines, and with the introduction of

Use of manholes and lampholes.

numerous manholes and lampholes, the whole system is brought under perfect control, and can be examined at any time without having recourse to breaking open the ground; and moreover any ordinary stoppage may be removed from the sewers with the aid of special tools applicable for the purpose, and which are applied at the manholes. The general arrangement of the sewers of a town will be seen from Plate I, which

Description of Plate No. 1.

represents the sanitary works of the town of Dantzic, in Prussia. From an examination of this plan, it will be seen that all the branch sewers are for the most part laid in straight lines, with manholes at all lateral deviations; the detail arrangement of the manholes of the minor sewers is shown in Plate IX. It will be ob-

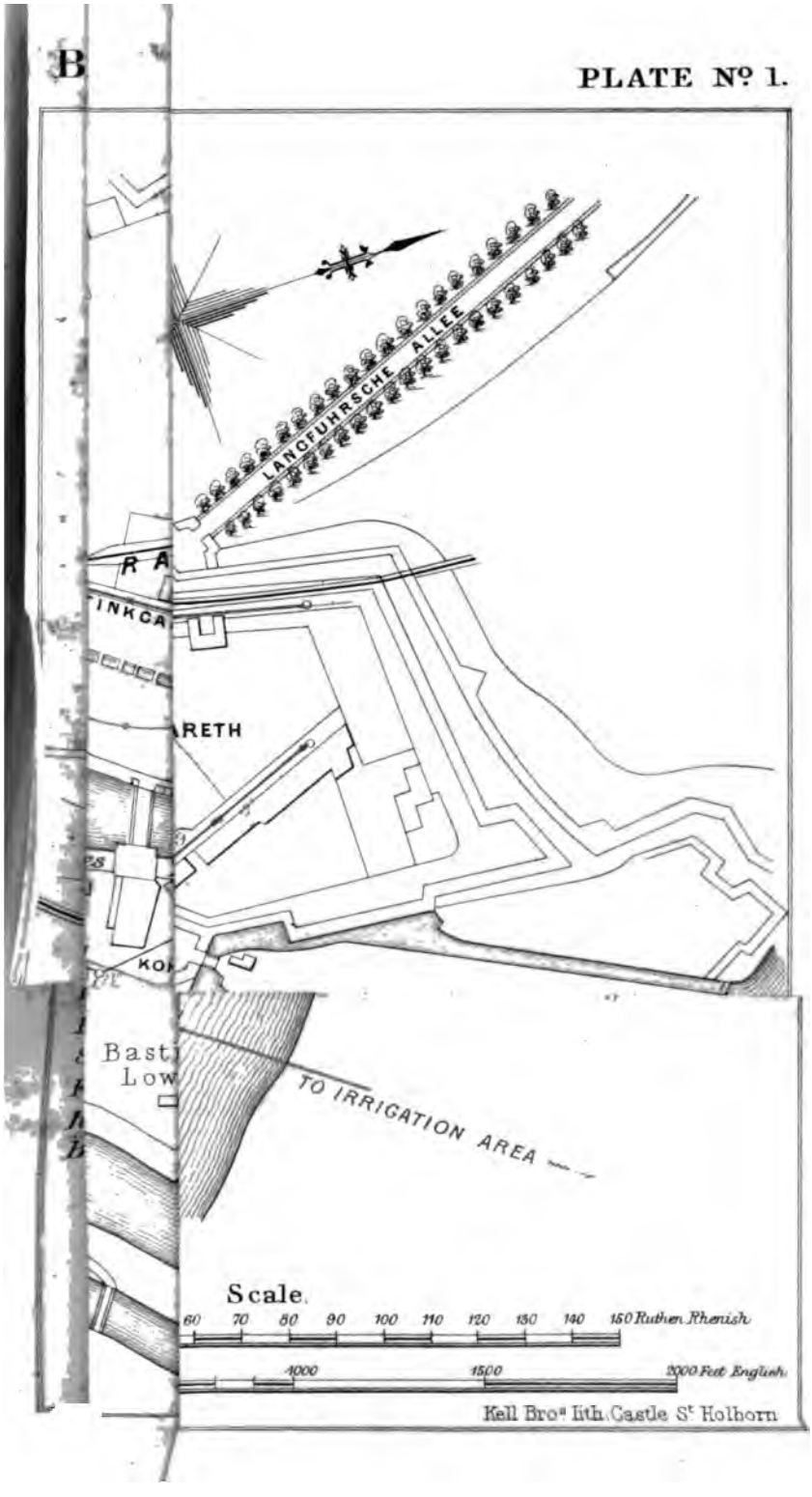
Description of Plate No. IX.

served from these detail arrangements, that in all cases in which more than one sewer enters a manhole, the sewer forming the principal outfall is constructed at a lower level than the sewers discharging into the manhole. This arrangement is adopted for two reasons,

Reasons for breaking up sewers in steps.

one being to aid ventilation,* as will be hereafter referred

* Vide page 243.


B
PLATE Nº 1.
LANGFUHRSCHE ALLEE
TO IRRIGATION AREA
Scale.
60 70 80 90 100 110 120 130 140 150 Ruthen Rhenish
1000 1500 2000 Feet English
Kell Bros lith. Castle St Holborn

to, and the other being to assist in the discharge of the sewers. For example, take Fig. 8, Plate IX., and we find three sewers, B, D, and E, all meeting at about the same level, but the sewer A, which has to discharge the contents of the other sewers, is situated at a lower level in order to assist the discharge, and so every sewer is provided with a free outfall. If this arrangement were not adopted we should find, at times, some inconvenience arise. For example, the general effect of a sudden enlargement in a sewer is to check the velocity. If the sewer D, Fig. 8, Plate IX., discharged into the sewer A, both sewers being of the same size, and having the same inclination, a loss of velocity would take place in passing the manhole C, and, therefore, if the sewer D at the time was running full bore, the sewage would head up in the manhole to such an extent as to make up for the head lost by the enlargement at the manhole, although in this case no evil would result. But supposing the sewers B and E enter the sewer at the same level, and one sewer is larger than the other, unless the manhole is of great size, the discharge of the larger sewer will interfere with the discharge of the smaller sewer. The author has seen a case in which, in time of storm, the smaller sewer could not discharge its contents, and it therefore flooded the neighbouring cellars. In the following woodcut, Fig. 11, is shown the mode in which stoppages are removed from modern sewers. The sewer-man has suspended a lighted lamp in the lamphole L, and has descended the manhole M, and with a series of tools attached to canes, similar to those used by chimney-sweepers, he is about to remove the stoppage. The man will be able to see when the sewer is clear, as between the manhole and lamphole the sewer is laid in a perfectly straight line, and so soon as the obstruction is removed, he will be able to see the light suspended at the lamphole. The tools used for the removal of stoppages are shown in Plate XXI., they speak for themselves. In addition

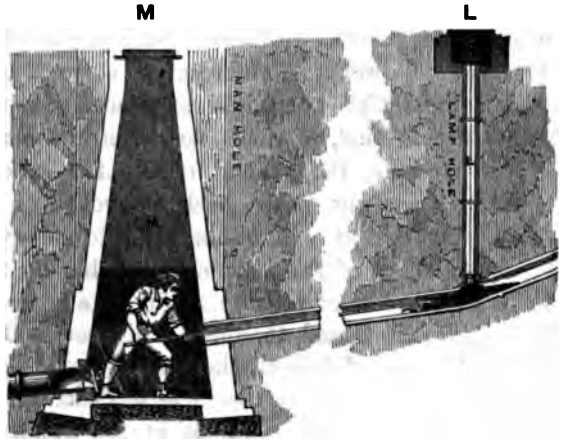
Removal of stoppages from sewers.

Tools used in removing stoppages, Pl. XXI

Sewer ploughs.

to these tools, others are not unfrequently used; as, for example, specially-constructed ploughs have been used

FIG. 11.




in large sewers, which are either drawn through the sewer by hand, or are propelled forward by the sewage being headed up behind them. A stout rope forms a very excellent tool for the removal of stoppage from small sewers or house-drains. The main lines of sewers are not necessarily laid in perfectly straight lines, but curves are introduced in their course; the resistance of these curves to the flow of the sewage diminishes in proportion to the smallness of the angle of divergence from straight lines, and with the greater radius of curvature. From the following formula the friction of bends may be arrived at.

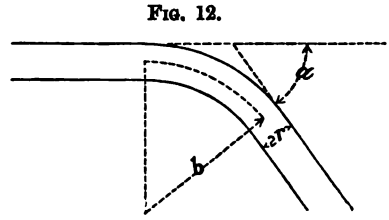
Friction of bends.

$h$ = head of water necessary to overcome the angular friction.
$v$ = velocity in feet per second.
$a$ = angle in degrees.
$r$ = radius of pipe,
$b$ = radius of the bend.
$2g = 64{\cdot}38$.
$c$ = coefficient.

$$h = c \times \frac{a}{90} \times \frac{v^2}{2g}; \text{ or,}$$

$$h = \frac{c}{579{\cdot}4} \times a \times v^2.$$

FIG. 12.



The coefficient $c$ is found by the formula—

$$c = \cdot131 \times 1\cdot847 \left(\frac{r}{b}\right)^{\frac{1}{2}}.$$

For,

| $\frac{r}{b} = 0\cdot1$ | ·2 | ·3 | ·4 | ·5 | ·6 | ·7 | ·8 | ·9 | 1·0 |
|---|---|---|---|---|---|---|---|---|---|
| $c = \cdot131$ | ·138 | ·158 | ·206 | ·294 | ·440 | ·661 | ·977 | 1·408 | 1·978 |

When bends are used it is usual to give the sewers a little extra fall in the bend to compensate for the increased friction.

Alternate lines of sewers used for discharge.

By the arrangement adopted of allowing the sewers all to join in manholes, it not unfrequently happens that if one line of sewer is blocked, another line may be used for the discharge. For example, in Plate IX., Fig. 7, we have the representation of a manhole in which three sewers run out, and only one runs into it. If any one of those three sewers were stopped, either of the other two would still furnish an outfall for the district above the manhole. By such an arrangement as this the area injuriously affected by a stoppage is reduced to a minimum.

Back drainage.

Much difference of opinion has been expressed as to the course in which sewers should be laid. The officers of the late General Board of Health insisted that back drainage was the proper plan to adopt; other authorities, equally eminent, have considered that less interference is caused with property, by constructing the public sewers in the public streets. The following woodcuts show the different systems. Fig. 13 is a representation of the plan of draining to the street, and Fig. 14 shows the same block of buildings draining to the back.

Economical considerations.

The author in the course of his experience has found that, as a rule, it is more economical to the local authorities, and far safer, to place the public sewers in the public thoroughfares than in private land at the back of houses. The modern system of sewers laid out in

straight lines, with manholes for inspection, so as to place the system of sewerage completely under control, is not applicable to back drainage, as manholes cannot be

Back and street drainage.

FIG. 13.

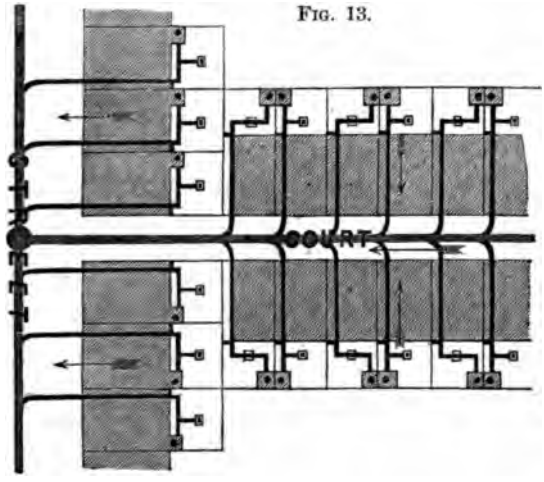
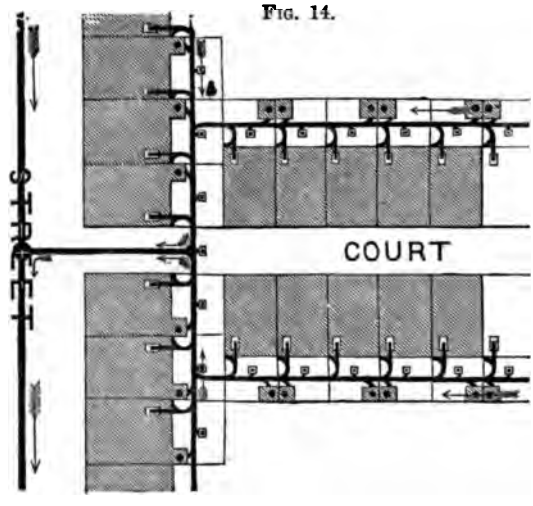



FIG. 14.




inserted on private property at the back of houses without serious inconvenience and encroachment on the rights and privileges of private citizens. To carry sewers through private property not unfrequently leads to much ill-feeling being manifested against the local

authorities, and, also, often entails great hardship upon the owners or occupiers of the premises. Moreover, a local authority has no power to construct sewers through private grounds, except by purchasing the right of easement, which in many cases has become a serious item of expense. The objection raised against the drainage to the street has arisen from having to carry house drains through or under the houses. This is an objection when house drains are imperfectly constructed, and would equally apply to back drainage, for unless we have sewers both at the front and back of the house, many houses would require the drains to be laid under them. To guard against the evils arising from accidents to house drains, the local authorities in new districts have power to introduce such building regulations so as to retain certain spaces about buildings to be erected, and where these spaces exist at the sides of the buildings the drainage can be brought from the back without traversing the house. In other cases an arrangement of passages may be left at the back of houses, in which the sewers can be constructed, so that the advantages of back drainage may be secured without the drawback of having the sewers constructed on property which it is not easy to get at. With perfectly constructed and well ventilated house drains, the evils of carrying them through or under houses are more imaginary than real, therefore the plea of perfecting the house drainage is no valid reason for the invasion of private property. There are many cases where it is necessary to carry public sewers through private property, but such cases should form the exception, and not the rule. In considering a system of sewers in reference to the general outfall, it will sometimes be found that it may be advisable to deviate from the lines of natural drainage of the district, and in order to secure a good outfall hills may be tunnelled, or valleys crossed with aqueducts or syphons. In carrying out a system of sewers, the natural streams should not be covered over and converted into sewers,

Objections against draining to the street.

Regulations in new districts.

Sewers carried through private property.

Outfall.

Natural streams should not be converted into sewers.

but such streams should be conveyed through the district, and be protected against pollution from sewage. These natural channels may often be improved so as to expedite the discharge of the surface water of the district.

## INTERCEPTING SEWERS.

Financial success depends on intercepting sewer.

The engineer who is charged with the design of works of sewerage should pay particular attention to the principle of interception. It may often happen that the financial success of a scheme for disposing of the sewage of a district will depend upon the construction of proper intercepting sewers, that is, certain portions of the sewage should be intercepted in the higher portions of the district, and not allowed to gravitate down to the lowest level, and so the sewage of a considerable portion of such district may often be conveyed by direct gravitation to a suitable outfall, leaving only the sewage of the lowest zones to be dealt with by artificial power. Not unfrequently the intercepting sewer will form the only outfall of the district, as the sewage of the lower district may be pumped into it.

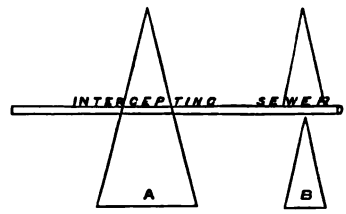
Districts in which interception should be carried out.

In districts in which there is but a small longitudinal fall, and comparatively great lateral falls, the work of interception will form an essential feature in the scheme of sewerage. In large towns the work of interception may be carried out with advantage, and thereby often reduce the cost of the system of sewerage, as when this principle is fully carried out, a large town is divided by intercepting sewers into a number of smaller areas, and as it is well known that it is much cheaper, proportionately to the population and area, to drain a small town than a large one, so a large town divided into districts by intercepting sewers can often be drained more effectually and cheaply than if all the sewers were allowed to flow to one common level. In fact, a branch sewer

Saving effected by interception.

may be compared to a cone, the base of which rests in the lowest portion of the district, and the apex terminates in the highest. A system of intercepting sewers would cut this cone, and the saving in cost would be represented by the difference in cost of constructing that portion of the branch sewer represented by the frustrum of the cone A, (Fig. 15) below the intercepting sewer, and the construction of another smaller cone B, the apex of which would commence at the intercepting sewer, and the base rest at the lowest level of the district, due allowance of course being made for any extra sewer that may be required in carrying out the principle of interception.

Fig. 15.




Large districts.

In large districts the principle of interception forms an essential element of safety: by dividing the drainage area into smaller districts the volume of sewage or rainfall is brought more under control than in districts where the volume of sewage is large, and is allowed to fall down to the lowest level of the district.

Sea-coast towns.

In sea-coast towns the principle of interception is also of great importance. The low-level sewers in such districts are often tide-locked; therefore it is of manifest advantage to intercept the sewage of the higher portions of the district, and to lead it away, together with the rainfall, by a district outfall, so as not to interfere with the tide-locked sewers of the district. The principle of interception is well understood in the great drainage works that have been carried out in the fen districts of this country.

Fen districts an example.

These large areas are entirely surrounded by intercepting drains, which catch the rainfall of the higher districts, and lead it off by gravitation to the natural streams, leaving only the rain falling on the low lands to be dealt with by artificial means. In many towns this principle of interception has formed a main feature in

London sewers. Districts that overgrow existing sewers.

the scheme of sewerage, as in the case of London it has received its full development. The author has seen many cases in which towns after being sewered have increased so rapidly in size and population that the original sewers have become too small, the consequence of which has been that the lower portions of the district have been frequently inundated. By the introduction into these overgrown towns of a system of intercepting sewers, cutting the sewers already constructed, the sewage of the upper portion of the district may often be harmlessly conveyed away, leaving the sewers of the lower district ample in size to deal with the volume of sewage which is locally due to them, and so, at a comparatively small cost, the efficiency of the original sewerage works may be restored.

## SECTIONAL FORM OF SEWERS.

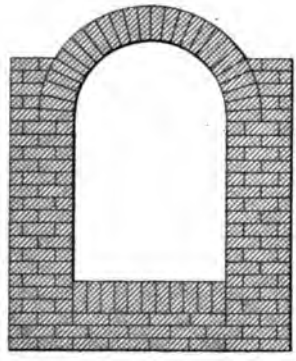
Correct form of importance.

A great variety of shapes for sewers has been adopted by various authorities at different periods. The adoption of a correct sectional form for the sewers of a district is a matter of primary importance, and when the object to be fulfilled by sewers is fully and scientifically considered, the correct shape to be adopted under varying circumstances may be easily arrived at. In practice sewers should be constructed of such a form as to convey away, with a maximum velocity, both the minimum and maximum flows, and they should also be constructed so as to ensure their stability without an unnecessary expenditure of material. The external forces acting upon a sewer are, the weight of the earth over the sewer acting in a perpendicular direction, and the weight of the earth pressing horizontally on the sides, the amount of the horizontal pressure depending on the angle of repose of the earth. The circular form is no doubt the strongest for all purposes of construction, because any pressure applied at any particular point is

Principles on which sewers should be constructed.

External forces acting on a sewer.

*Fig: 1.*



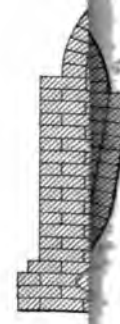


*Fig: 5.*

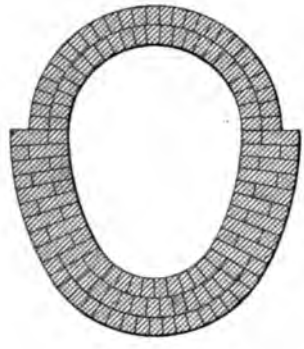
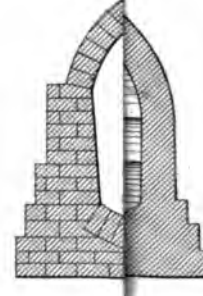


*Fig: 9.*



Kell. Bros Lith

Fig: 1.

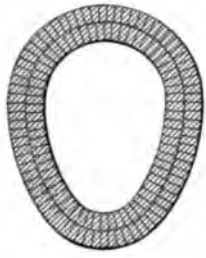


Fig: 4.

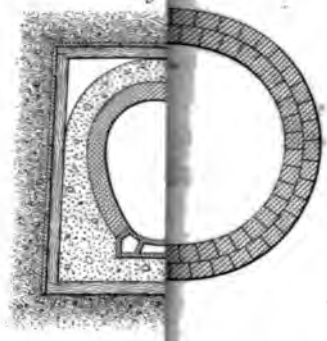


Fig: 5.

Fig: 9.

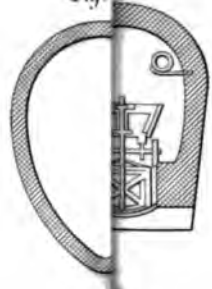


Fig: 10.

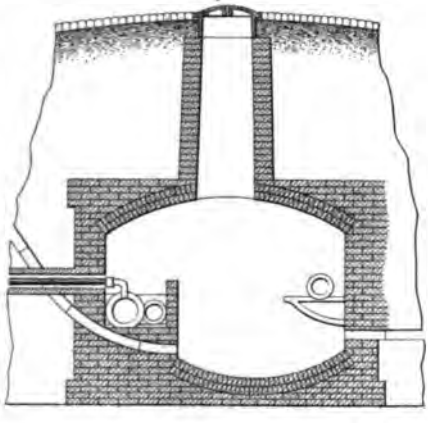


Fig: 14.

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distributed throughout the whole structure. Theoretically, as the pressure is greatest vertically, and least horizontally, an elliptically-shaped sewer would best resist the forces at work tending to crush it. In the construction of sewers, the external pressure the sewer has to bear is but one, and not the primary, element that has to be considered, for it has already been noted that a certain minimum velocity is required in all sewers that are to be self-cleansing; and when considering the question of the flow through the sewer, the less the area of the wetted perimeter, in proportion to the sectional area, by so much will the velocity of flow be increased.

Sewers with intermittent flow.

It is therefore advisable to adopt, for sewers having an intermittent flow, such a sectional form as to ensure the greatest velocity, when the smallest volume is flowing through them, and for this reason all sewers that are subject to constant fluctuation in the flow, the egg-shaped form will be found to be the best.

Sewers with uniform flow.

In sewers in which the amount of sewage to be conveyed is great, and pretty uniform, the circular form answers best, as it is cheaper and stronger when constructed.

Description of Plate II.

In Plate II. are shown a number of sewers of various sections that have from time to time been used.

Roman sewer.

Fig. 1 represents the form generally adopted by the Romans; it is constructed with a flat invert, straight sides, and with a semicircular arch.

Sewer of period of Charles II.

Fig. 2 is an improvement on the Roman type. This form was introduced into England, by special ordinance, in the reign of Charles II. In this case the invert is slightly curved, the sides being straight, and the arch semicircular.

Improved shape.

Fig. 3 shows a still further improvement on Fig. 2, the invert in this case being made semicircular, like the arch. Fig. 4 is a still further improvement, adopted in some of the London sewers, in which the curved invert is reduced to a smaller circle than that of the arch. Fig. 5 is a still further improvement, in which the invert, sides, and arch are curved. This form has been used in Westminster, Lambeth, and Finsbury. Fig. 6 represents a form of sewer similar to that of Fig. 5, except that the

sewer is inverted, the larger circle forming the invert, and the smaller the arch. This form was once used in Westminster, but with no very great success. Fig. 7 represents an egg-shaped sewer constructed in stonework, as used in Edinburgh. Fig. 8 represents an elliptical sewer, as used at Westminster. Fig. 9 represents an oval sewer, as used by Mr. J. Phillips in Westminster. The mode of striking out this sewer is shown in Fig. 17, page 101. Fig. 10 represents a form which was generally used when constructing large sewers in the early London sewerage works. This form of sewer was found to be very liable to stoppage, being generally constructed of a size totally out of all proportion to the wants of the district which it was intended to drain, consequently sedimentary deposit collected in the angles, which greatly retarded the velocity. Fig. 11 represents an oval sewer, used in the London districts, which is a great improvement on that of Fig. 10. Fig. 12 is a similar sewer to that of Fig. 10, the only difference being the mode in which the sewer was built up, Fig. 10 as a work of construction being preferable to that of Fig. 12, but both are inapplicable in the construction of ordinary town sewers. Fig. 1, Plate III., represents the section of a modern egg-shaped sewer built entirely of brickwork: it is a correct representation of the outfall sewer constructed by the author at Redhill. Fig. 2 is a representation of the outfall sewer constructed by the author at Reigate. The section is taken at the point where the sewer passes under Park Hill, in tunnel. Fig. 3 is a representation of the outfall sewer of Reigate, at a point where it is carried in embankment. The two small sewers used in this case are equal in discharging capacity to the oval sewer Fig. 2. This form was adopted in order to reduce the height of the embankments, and arrangements are made at the ends of the double sewer, so that, when there is a small stream flowing through the sewers, it can be diverted entirely through one or other of the sewers. Fig. 4 represents a circular sewer executed in brickwork. Fig. 5 repre-

Large London sewers.

Oval London sewers.

Description of Plate III.

Redhill sewer.

Reigate sewer.

sents a section of a sewer as used at Southampton, with a flat invert; for the conveyance of small volumes of sewage this form of sewer cannot bear comparison with the ordinary egg-shaped sewer. Probably the shape was adopted for the convenience of cleansing, as the flat invert formed a better footway for the men traversing the sewer than the sharp curves of the invert of the ordinary oval sewer. Fig. 6 represents the section of an earthenware-pipe sewer used a few years ago. This form is not now generally used, as it is found that there is some difficulty in making the pipes of true section, and consequently when laid they form an imperfect sewer. Fig. 7 represents the section at a junction of two oval sewers, showing the way in which the sewers are joined. Fig. 8 represents a plan and section showing the junction of three sewers, and the way in which these communications are usually formed. Fig. 9 represents a section of a Paris sewer, the sewer proper occupying the small space shown below the truck. On each side of the sewer rails are fixed, upon which a truck, carrying a disc, fitting into the sewer, is made to travel, the sewage heading up at the back of the disc propels the apparatus forward. When the sediment increases in front of the disc to such an extent as to impede its progress, the truck is drawn forward, and the solid matter is taken from before the disc, and thrown into the truck. It should be observed that round the edge of this disc are numbers of small holes, and as the water heads up behind the disc it is discharged with a certain velocity, through the holes, and so washes away the sediment immediately in front of the disc, and thus somewhat accelerates the progress of the apparatus. The gas and water pipes, were inserted in the subway of the sewer as shown, fixed upon brackets, but it has been found by experience that the introduction of gas-pipes into these combined subways and sewers is attended with some inconvenience and danger, and of late they have been removed. In order to obviate the difficulties

Southampton sewer.

Oval pipe sewer.

Paris sewer.

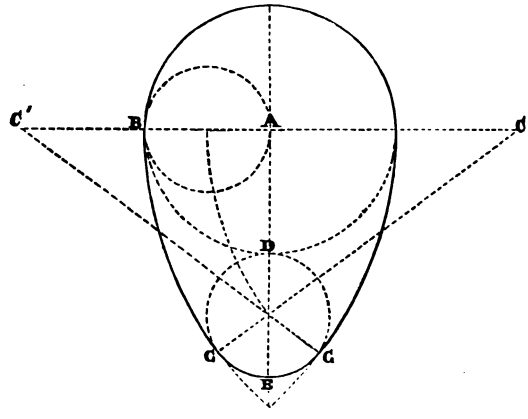
which had arisen from the insertion of gas mains into sewer subways, M. Versluys, in a drainage project for Brussels, proposed to introduce another form of sewer and subway, which is shown in Fig. 10, the water-pipes in this case being arranged on brackets on one side of the sewer, the gas-pipes being laid in a long series of troughs of water on the other side, the idea being that the gas-pipes being laid in water of greater depth than the pressure within the pipe, would check the tendency of the gas to escape; but this suggestion has not at present been acted upon, and the plan remains untried.

Proposed Brussels sewer.

Advantages of oval sewers.

In studying the best form of sewer, Figs. 11, 12, and 13 show at once the advantages of the oval over other forms given in these figures. It will be seen from these figures that with the oval sewer a greater depth of sewage, with a less surface, is maintained, than in any other form; therefore, in all cases in which the volume of sewage is liable to fluctuation, the oval or egg-shaped form should invariably be adopted. Fig. 14 represents an earthenware pipe sewer constructed in tunnel. The following woodcut, Fig. 16,* shows the

FIG. 16.




mode adopted in striking out modern egg-shaped sewers. In some cases it may be desirable to adopt the egg-

* The proportions of this sewer are given in the description of Table No. 12, page 54.

shape, but with dimensions differing from the above proportion, as, for example, when carrying a sewer in an embankment, or when the shallowness of the cutting will not permit of the full vertical depth being given to the sewer, in which case the proportion of egg-shaped sewers, having smaller vertical dimensions than one and a half times the transverse diameter, may be found by the following formula, which was described in a paper by Mr. S. A. Reade, M.A., read before the Society of Engineers.

Formula for oval sewers.

$$(1)\ \mathrm{R} = \tfrac{1}{2}\left(\frac{d^2}{r - r_1} + r + r_1\right).$$

$$(2)\ \mathrm{A} = \frac{\pi}{180}\left\{a(\mathrm{R}^2 - r_1^2) + 90(r^2 + r_1^2)\right\} - d(\mathrm{R} - r).$$

$$(3)\ \mathrm{C} = \frac{\pi}{90}\left\{a(\mathrm{R} - r_1) + 90(r + r_1)\right\}.$$

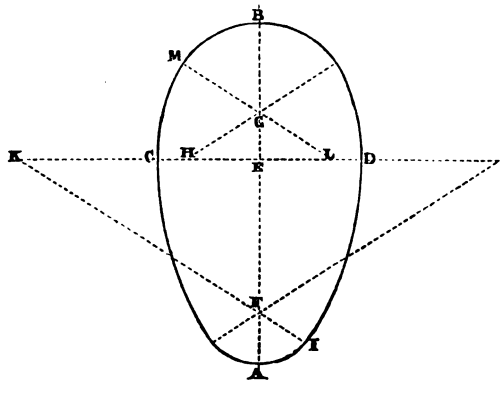
R being the radius of the side;
$r$ of the arch;
$r_1$ of the invert;
$d$ the distance between the centres of the circles, or equal the depth minus $r + r_1$;
A is the area;
C the circumference;
$a$ the angle which is subtended by the arc forming the sides, and may be found from its sine or tan.; for

$$\text{sine } a = \frac{d}{\mathrm{R} - r_1},\ \text{tan. } a = \frac{d}{\mathrm{R} - r};$$

$\pi = 3{\cdot}14159$.

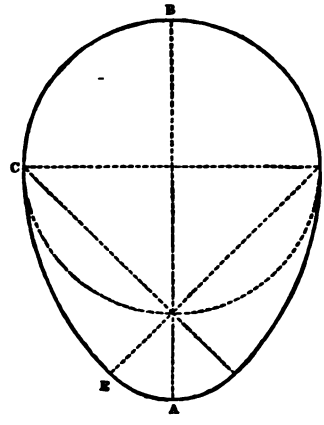
Other modes have been adopted for setting out oval sewers; for example, Fig. 17 represents the mode

FIG. 17.



adopted by Mr. Phillips in the construction of oval sewers. In this case AB = 1⅓ CD; AE = CD; AF = ¼ of CD; GE = ¼ of CD; CH = ⅛ of CD; and IK is parallel to LM. Fig. 18 shows another mode of setting out the section of oval sewers; this form of sewer was designed by Mr. T. Hawksley, C.E. It is somewhat easier of construction, but is not such a perfect carrier for sewage, when the quantity is reduced to a comparatively small volume, as the sewer described in Fig. 16. In this case DE = CD. Mr. Hawksley gives the following particulars respecting this form of sewer: as compared with a circular sewer of the same diameter the area is "as 996 to 785 = 1·27 to 1; therefore when the areas are equal the diameters will be as 8 to 9 nearly," and from hence he lays down the following rules. 1. Find "the diameter of the circular sewer capable of affording the requisite amount of drainage, deduct its ninth part, the remainder is the horizontal diameter of the equivalent oval sewer." 2. "Add one-eighth to the diameter of an oval sewer, the sum is the diameter of the equivalent circular sewer; the discharge, declivity, and drainage area," will be the same as for the circular sewer so found.

Fig. 18.




Small sewers, circular.

For all ordinary purposes it is found in practice that sewers up to 18 inches internal diameter are best constructed in earthenware, and circular in section. This form of pipe is less liable to be distorted in the process of manufacture than oval sewers, and, moreover, any little irregularity in section can be modified, from the fact that the circular pipes may be turned round, and

if they do not fit and make a good joint one way, they may often be made to lie true on the invert by a little manipulation. Irregularly-shaped pipes should not be allowed to be used for sewers, but if, from mischance, they do get into the work, the evil is less in circular-pipe than in oval-pipe sewers, as the ill effects may be modified, and moreover the percentage of distorted pipes is far less for circular than for oval pipes, so that there is less chance of their being used in the work. In sewers of larger diameter than 18 inches it should be the rule, that when there is sufficient sewage to maintain the sewer constantly running half full, and when the same sewer flows nearly full, it will be sufficient in size to carry off the maximum flow required, then the sewer should be made circular in section, as this is both the cheapest and strongest form of sewer. In all other cases, or when the fluctuation of the flow varies within greater limits than stated for circular sewers, the section should be egg-shaped, excepting only the case of very small sewers, which may be circular.

Rule for sectional form of large sewers.

## MATERIALS EMPLOYED IN THE CONSTRUCTION OF SEWERS AND THEIR MODE OF APPLICATION.

The materials that have from time to time been used in the construction of sewers, are bricks of all kinds, tiles, stone, stoneware, artificial stone, asphalte, cement, concrete, iron, and timber. Experience has demonstrated that, in order to secure the permanency and durability of sewer work, great care is required in the selection of a proper material, and that the best materials procurable are the cheapest in the end. The inverts of sewers are particularly liable to wear from the erosion of the water, and from the grinding action of the sand and solid matter transported over them. There are few brick

Different kinds of material.

Wear of sewer inverts.

sewers in London of greater age than fifty years which have not been underpinned, and provided with new inverts, and otherwise extensively repaired, on account of the destruction which has taken place from the above-named causes. In selecting materials for the construction of sewers, great care should be used in order to secure those which will be least liable to be affected, either by the chemical qualities of the sewage, the gases found in sewers, or by the mechanical action of the flowing stream, or the materials transported over its bed.

Selection of materials.

Sewer pipes.

Small sewers and house drains are now usually constructed of glazed stoneware or fire-clay pipes. It is not yet a quarter of a century since pipes of this description were first used as sewers, but in that limited space of time vast numbers have been manufactured, until the trade has become of such importance that it may be looked upon as one of the principal industries of the country. In the early days of the manufacture of sewer pipes, when little was known either as to the strength or durability of the material, or of its mode of application, failures resulted from the injudicious haste with which they were used, in large quantities, without any test being applied as to their ability to withstand the strains to which they would be subjected. As a rule, all the early sewer pipes were made too thin to withstand the pressure of the earth in deep cuttings and were very unequally and very insufficiently burnt. As an example, the case of Croydon may be taken, which was the first town that extensively adopted the pipe system. In this town 15-inch earthenware pipes were laid in cuttings over 20 feet deep, and as they were not over well burnt, and had but a thickness of $\frac{8}{9}$ths of an inch, or almost the thickness of a modern 6-inch pipe, no wonder that, as soon as the pressure of the earth was brought to bear on them, the sewer collapsed, and in order to save the portions not filled in it became necessary to throw a brick arch over the

Failure of sewer pipes.

Failure of pipes at Croydon.

pipes to take the strain. At the present time pipes both of stoneware and fire-clay are extensively and satisfactorily used. Fire-clay pipes are not generally considered, thickness for thickness, as strong as stoneware pipes. There are many other descriptions of sewer pipes now in general use, which alternate between these two, and it will always be a point for the engineer to consider under what class or description his pipes shall be classified.

Stoneware and fire-clay pipes.

At the present time stoneware and fire-clay pipes are made of the dimensions and thickness given in Table 25.

TABLE No. 25.

Dimensions of sewer pipes.

| STONEWARE. | | | | FIRE-CLAY. | | | |
|---|---|---|---|---|---|---|---|
| Internal Diameter. | Thickness. | Length in Work. | Depth of Socket. | Internal Diameter. | Thickness. | Length in Work. | Depth of Socket. |
| ins. | ins. | ft. | ins. | ins. | ins. | ft. | ins. |
| 3 | $\frac{3}{8}$ | 2 | $1\frac{1}{2}$ | 3 | $\frac{3}{8}$ | 2 | $1\frac{1}{2}$ |
| 4 | $\frac{3}{8}$ | 2 | $1\frac{1}{2}$ | 4 | $\frac{3}{8}$ | 2 | $1\frac{1}{2}$ |
| 6 | $\frac{3}{8}$ | 2 | $1\frac{3}{4}$ | 6 | $\frac{3}{4}$ | 2 | $1\frac{3}{4}$ |
| 9 | $\frac{3}{4}$ | 2 | 2 | 9 | $\frac{3}{4}$ | 2 | 2 |
| 10 | $\frac{7}{8}$ | 2 | 2 | 10 | 1 | 2 | 2 |
| 12 | 1 | 2 | 2 | 12 | $1\frac{1}{10}$ | 2 | 2 |
| 15 | $1\frac{1}{8}$ | 2 | $2\frac{1}{4}$ | 15 | $1\frac{1}{4}$ | 2 to 3 | $2\frac{1}{4}$ |
| 18 | $1\frac{1}{4}$ | 2 to 3 | $2\frac{1}{2}$ | 18 | $1\frac{1}{2}$ | 2 „ 3 | $2\frac{1}{2}$ |

Insufficiency of thickness.

In the course of his experience, the author has found, in some cases, that the thickness given in the above Table for fire-clay pipes is not sufficient. In one case especially which came under his notice, a sewer 18 in. internal diameter, constructed of fire-clay pipes, having a thickness of $1\frac{1}{2}$ in., was laid in a cutting about 16 ft. deep, and filled in, in wet weather, with clay of a very unstable character, when it was found that so soon as the pipes had become thoroughly saturated with moisture, and had taken the pressure of the superincumbent earth, they altered in shape, and the vertical diameter, being no longer 18 in., was reduced to 15 in., when in order to prevent a collapse of the sewer, the whole of the pipes were removed, and a brick sewer substituted. It was found in a few days after the

removal of these pipes, that they had returned to their circular shape, and were subsequently used in a shallower cutting. From this it will be seen that great care and caution is required in the selection of the pipes to be used in works of sewerage when executed in deep cuttings and in unstable ground. The best quality of pipes for sewers are those made of a vitreous imperishable material of sufficient strength to resist fracture, having toughness enough to resist shocks, being tenacious, hard, homogeneous, impervious in character, uniform in thickness, true in section, and perfectly straight, uniformly glazed both inside and outside, free from fire or other cracks, and when struck should ring clearly. Porous substances are not so good as those that are vitreous throughout, and pipes burned at a low temperature are not so good as those that have been subjected to a higher temperature. Pipes that are salt glazed are more durable, and preferable to those lead or glass glazed. The impermeability of a pipe may be taken as an element of its durability and fitness for sewer work, as the more impervious a pipe is the better will it prevent the entrance into the interstices of the material of those agents which are likely to exercise a destructive influence upon it—such as, for example, the crystallization of water in time of frost, or the formation of crystals in the presence of certain chemical compounds, or the direct chemical action of some materials found in sewers on the material itself, and which will sooner or later effectually destroy the pipe. Pipes are tested for impermeability by first drying the pipe till it ceases to lose weight, and then submerging it in water, allowing it to remain at least 24 hours under water, then removing it from the water, wiping dry, and re-weighing. Table No. 26 shows the results of some experiments made by the author on sewer pipes.

Care must be exercised in selecting pipes.

Quality of good pipes.

Porous pipes objectionable.

As a test of sewer pipes to resist the action of certain chemicals which in some towns are allowed to enter the sewer, the method adopted is to take a piece of the

Test of sewer pipes to resist chemical action.

pipe and pulverize it, then to boil it in hydrochloric acid, subsequently to wash on a filter, and dry, noting the loss in weight. Dr. W. A. Miller showed some years ago that stoneware pipes could be boiled in muriatic acid without suffering loss in weight—hence the repute in which utensils of this description are held by the manufacturers of chemicals. The impermeability of a

Test of impermeability.

TABLE No. 26.—Showing the ABSORPTION of WATER by SEWER PIPES.

| Name of Maker. | Size of Pipe as measured. | Length of Pipe as measured, exclusive of Socket. | Thickness of Pipe. | Weight in lbs. when Dry. | Weight in lbs. after 24 hours immersion in Water. | Amount of Water absorbed. | Percentage of Water absorbed by Dry Pipe. |
|---|---|---|---|---|---|---|---|
| | ins. | ft. in. | ins. | lbs. | lbs. | lbs. | |
| Doulton and Co., London pipe .. .. | 6 | 1 11 | ·75 | 31 | 31·25 | ·25 | ·806 |
| " " | 6 | 1 11 | ·72 | 29·5 | 29·75 | ·25 | ·85 |
| S. Fisher .. .. .. | 6 | 2 0 | ·63 | 28 | 28·75 | ·75 | 2·68 |
| Wortley pipe .. .. | 6 | 1 11 | ·74 | 30·5 | 31·75 | 1·25 | 4·10 |
| Ingham, Wortley .. | 5 | 1 11 | ·69 | 26·0 | 26·5 | ·50 | 1·92 |
| Huddersfield pipe .. | 9 | 2 4 | ·92 | 73 | 73·75 | ·75 | 1·03 |
| Doulton and Co., London pipe .. .. | 9 | 2 0 | ·87 | 57·75 | 58·75 | 1·00 | 1·73 |
| Doulton and Co., Staffordshire pipe .. | 9 | 1 11 | ·87 | 51·75 | 53·00 | 1·25 | 2·41 |
| Cliff, Wortley .. .. | 9 | 2 4 | ·81 | 60·5 | 63·25 | 2·75 | 4·54 |
| Aylesford pipe .. .. | 9 | 2 0 | 1·00 | 58·0 | 62·00 | 4·00 | 6·89 |
| Doulton and Co., Staffordshire pipe .. | 12 | 2 0 | 1·05 | 96·0 | 97·5 | 1·50 | 1·56 |
| S. Fisher .. .. .. | 12 | 1 11 | 1·00 | 84·0 | 88·0 | 4·00 | 4·76 |
| Stiff and Sons .. .. | 12 | 1 10 | 1·02 | 66·25 | 67·5 | 1·25 | 1·88 |
| Wilcox and Co., Wortley .. .. .. .. | 12 | 1 11 | 1·03 | 79·5 | 82·5 | 3·00 | 3·77 |
| Doulton and Co., London pipe .. .. | 15 | 1 11 | 1·06 | 116·5 | 117·0 | ·50 | ·429 |
| Doulton and Co., Staffordshire pipe .. | 15 | 2 6 | 1·26 | 132·0 | 139·0 | 7·00 | 5·30 |
| Stiff and Sons .. .. | 14 | 1 10 | 1·06 | 105·75 | 108·75 | 3·00 | 2·83 |
| Wilcox and Co. .. | 15 | 1 10 | 1·72 | 130·00 | 137· | 7·00 | 5·38 |
| Ingham and Sons .. | 15 | 2 6 | 1·31 | 165·0 | 174·5 | 9·50 | 5·75 |
| Doulton and Co. .. | 18 | 2 4 | 1·43 | 221·0 | 226·00 | 5·00 | 2·26 |
| " " .. | 18 | 2 5 | 1·38 | 210·0 | 217·0 | 7·00 | 3·33 |

pipe may be tested by tying a piece of bladder, or other suitable substance, over one end of the pipe, then reversing it and filling it with water. If the material is not perfectly impervious it will soon be detected by the sweating of the pipe, as it is termed, or the appearance of water oozing on the outside, together with the loss of

Tensile strength of pipes.

water from the interior of the pipe, which will require to be replenished if the pipe is very permeable. The tenacity of the material of which sewer pipes are manufactured is a quality that varies immensely, even in pipes manufactured at the same time and place. There are so many circumstances which arise during the process of manufacture that may alter the character of the finished article, that pipes of this description, when required to resist tensile strain such as would arise when they are working under pressure, cannot be recommended for use; therefore in all cases when considerable pressure may have to be sustained it is better to use iron. From Table No. 27, which gives the

TABLE No. 27.—Showing the BURSTING PRESSURE and TENSILE STRAIN of EARTHENWARE PIPES.

| Name of Maker. | Where made. | Size of Pipe. | Length of Pipe. | Thickness of Pipe. | Bursting Pressure in lbs. per square inch. | Tensile Strength per square inch in lbs. |
|---|---|---|---|---|---|---|
| | | ins. | ft. in. | ins. | | |
| Doulton and Co. | Staffordshire. | 6 | 1 11 | ·65 | 50 | 230·7 |
| " " | London .. | 6 | 1 11 | ·72 | 10 | 41·6 |
| Ingham and Co. | Wortley .. | 6 | 1 11 | ·48 | 4 | 25·0 |
| " " | " .. | 6 | 1 11 | ·69 | 70 | 304·3 |
| S. Fisher .. " .. | London .. | 6 | 2 0 | ·57 | 15 | 78·9 |
| T. H. Seacombe | Ruabon, North Wales | 6 | 1 10½ | ·70 | 5 | 21·4 |
| Aylesford .. | Aylesford .. | 9 | 2 0 | 1·00 | 45 | 202·5 |
| Doulton and Co. | London .. | 9 | 2 0 | ·84 | 40 | 214·2 |
| " " | Staffordshire. | 9 | 1 11 | ·79 | 20 | 113·9 |
| Cliff .. " .. | Wortley .. | 9 | 2 4 | ·84 | 60 | 321·4 |
| Brookes .. .. | Huddersfield | 9 | 2 6 | ·91 | 55 | 271·9 |
| T. H. Seacombe | Ruabon, North Wales | 9 | 1 11 | ·94 | 30 | 143·6 |
| Doulton and Co. | Staffordshire. | 12 | 2 0 | 1·07 | 7 | 39·2 |
| Wilcox and Co. | Wortley .. | 12 | 1 11 | ·94 | 7 | 44·6 |
| Stiff and Sons . | London .. | 14 | 1 10 | ·95 | 30 | 221·0 |
| Doulton and Co. | Staffordshire. | 15 | 1 10 | 1·10 | 20 | 136·3 |
| " " | London .. | 15 | 2 5 | 1·19 | 33 | 207·9 |
| " " | " .. | 15 | 2 5 | 1·25 | 15 | 90·0 |
| Ingham and Co. | Wortley .. | 15 | 2 5 | 1·15 | 20 | 130·4 |
| T. H. Seacombe | Ruabon, North Wales | 15 | 1 10 | 1·10 | 63 | 429·5 |

results of experiments by the author, it will be seen that the tenacity of material varies from 21·4 lbs. per

square inch to 429·5 lbs. per square inch of section, a range sufficiently great to show its uncertainty and variableness.

Strength to resist percussion.

With regard to the quality of the material used in the manufacture of sewer pipes to resist percussive action, such as, for instance, they have often to bear when earth is carelessly thrown into a trench, or the trench is rammed when there is but a thin layer of earth over the pipe, or the pipes are subjected to the jar of heavy traffic. It has been found that for all practical purposes, when the work of refilling the sewer trenches is carefully performed, the material in general use for constructing sewer pipes has sufficient toughness to resist these strains. In May, 1856, some experiments were made with sewer pipes at the works of Messrs. Burton and Waller, of Southwark, to ascertain their capability to resist shocks. For this purpose a cast-iron ball 14 lbs. in weight was allowed to fall on the pipe from the heights of 4, 5, 6, and 7 inches; the percussive action being equal to the velocity multiplied by the weight may be taken as follows:—

Percussive action.

| | | |
|---|---|---|
| 4 inch | fall | = 64·65; |
| 5 | „ | = 72·47; |
| 6 | „ | = 79·38; |
| 7 | „ | = 85·74. |

Table No. 28 shows the results of the experiments.

Crushing of sewer pipes.

Pipes when laid, and acting as a sewer, are always more or less exposed to the crushing action of the superincumbent earth, therefore they must be made of sufficient thickness to resist the pressure likely to be brought upon them. Sewer pipes of the thickness given in Table 25 are sufficiently strong for all practical purposes, but when laid in deep cuttings in treacherous earth the thickness should be slightly increased. Experiments have been made in order to ascertain the amount of force required to crush pipes of various kinds. Table 29 has been compiled from experiments made before Mr. J. W. Bazalgette, C.E.,

in 1855, and before Mr. William Haywood, C.E., in 1856. For the purpose of experiment each pipe was placed on two flat pieces of hard wood, and a piece of

Table 28. Percussive action.

TABLE No. 28.—EXPERIMENTS on EARTHENWARE PIPES to RESIST PERCUSSIVE ACTION, made at Messrs. BURTON and WALLER'S Works, Holland Street, Blackfriars, 15th May, 1856.

| Name of Maker. | Diam. of Pipe in Inches. | Thickness of Pipe in Inches. | Weight of Pipe in lbs. | Number of Pieces when Broken. | Remarks. |
|---|---|---|---|---|---|
| Doulton . | 6 | ·75 | 35 | 2 | After six blows with 4" fall, pipe perfect; 2nd blow, 5" fall, pipe cracked; and 7th, pipe broke. |
| ,, .. | 6 | ·75 | 35·25 | .. | 4th blow, 5" fall, cracked pipe; 7th, pipe broke. |
| Aylesford | 6 | ·75 | 33·5 | 2 | 4th blow, 5" fall, made hole in pipe 3·5"×2·5"; pipe then turned over, and 2nd blow cracked and 4th pipe broke. |
| ,, .. | 6 | ·75 | 32 | 2 | 2nd blow with 5" fall, pipe cracked; 6th blow, pipe broke. |
| ,, .. | 6 | ·75 | 32·75 | 2 | Pipe had been soaked in water; 2nd blow with 5" fall, pipe slightly cracked; 3rd, pipe completely cracked; 5th blow, small hole; the 36th blow, hole 3·25"×2·5"; pipe then turned over and broke the 2nd blow. |
| Doulton . | 9 | ·875 | 63·5 | 2 | After six blows with 5" and 6" falls, pipe perfect; the 2nd blow with 7" fall, pipe cracked; and 5th blow, pipe broke. |
| ,, .. | 9 | ·937 | 62·75 | 2 | 2nd blow with 7" fall cracked pipe; 4th, pipe broke. |
| Aylesford | 9 | 1·00 | 60·5 | .. | Pipe soaked in water, the 1st blow with 7" fall, pipe cracked; 8th made small hole; 31st, transverse fracture; 34th, pipe broke. |
| ,, .. | 9 | 1·00 | 60·25 | 2 | 1st blow with 7" fall, pipe slightly cracked; 6th made small hole; 36th, hole 3·75"×2·75"; pipe then turned and broke 1st blow. |
| Doulton . | 12 | ·937 | 89 | 2 | 1st blow with 7" fall cracked it; 2nd blow, pipe broke. |
| ,, .. | 12 | 1·00 | 97 | .. | 3rd blow with 7" fall, pipe cracked; 6th blow, piece flew out of pipe; 16th blow, large piece out of the bottom of pipe; 20th, hole in top of pipe; 29th, top shivered; 45th, broken up. |

hard wood was laid on the top of the pipes, the weight being applied by means of a lever, as shown in Fig. 19. In some of the experiments a packing of felt was placed round the pipe. From an examination of the

Table it will be seen that the material has a pretty uniform character for resisting crushing strains, therefore can be depended upon when placed in positions liable to such strain. Table 29. Crushing of Sewer Pipes.

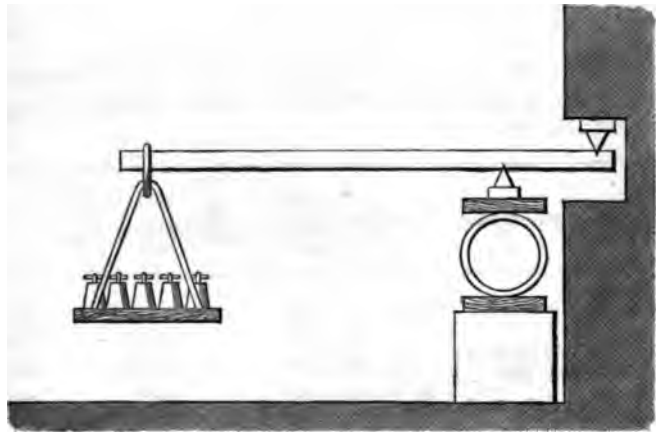
TABLE No. 29.—EXPERIMENTS on the CRUSHING of EARTHENWARE SEWER PIPES, conducted at the WORKS of Messrs. BURTON and WALLER, Holland Street, Blackfriars.

| Date of Experiment. | Maker's Name. | Diameter of Pipe in Inches. | Thickness of Pipe in Inches. | Weight of Pipe in lbs. | Breaking Weight in lbs. | Number of Pieces of broken Pipe. | Remarks. |
|---|---|---|---|---|---|---|---|
| 1855. | | | | | | | |
| July 18 | Doulton . | 8⅛ × 8⅛ | ·75 | .. | 2713 | .. | Without felt pad. |
| " " | " .. | 8⅛ × 8⅛ | ·75 | .. | 2470 | .. | With felt pad. |
| " " | Aylesford pipe .. | 8⅛ × 8⅛ | 1·00 | .. | 2106 | .. | Without felt pad. |
| " " | " " .. | 8⅛ × 8⅛ | 1·00 | .. | 3077 | .. | With felt pad. |
| " " | Stiff .. | 8⅛ × 9 | ·812 | .. | 2106 | .. | Without felt pad. |
| " " | " .. | 8⅛ × 9 | ·812 | .. | 2228 | .. | With felt pad. |
| " " | Doulton .. | 11½ × 11¾ | 1·00 | .. | 3684 | .. | Pipes placed with largest diameter vertical. |
| " " | " .. | 11½ × 11¾ | 1·00 | .. | 3684 | .. | |
| " " | Aylesford | 12¼ × 12¼ | 1·125 | .. | 2936 | .. | Felt pad round pipe. |
| " " | " .. | 12¼ × 12¼ | 1·125 | .. | 2470 | .. | " " |
| " " | Stiff .. | 11¾ × 12 | 1·00 | .. | 2834 | .. | " " |
| " " | " .. | 11⅞ × 12 | ·937 | .. | 2713 | .. | " " |
| 1856. | | | | | | | |
| May 2 | Boucher . | 6 | ·75 | 33·5 | 2956 | .. | Pipe hard and well burnt. |
| " " | Pilton .. | 6 | ·75 | 33 | 1864 | .. | Aylesford pipe, not of true section, rather oval. |
| " " | Boucher . | 9 | ·875 | 63 | 2228 | .. | |
| " " | Pilton .. | 9 | 1·06 | 66 | 2775 | .. | Aylesford pipe. |
| " " | Boucher . | 12 | ·935 | 91 | 2410 | .. | |
| " " | Pilton .. | 12 | 1·125 | 94 | 2228 | .. | " " |
| " 15 | Doulton .. | 6 | ·75 | 35 | 2713 | 5 | Transverse fractures. |
| " " | " .. | 6 | ·75 | 35 | 2531 | 6 | |
| " " | Pilton .. | 6 | ·75 | 33·5 | 1803 | 5 | Longitudinal fractures in nearly parallel pieces. |
| " " | " .. | 6 | ·75 | 32·5 | 1742 | 5 | |
| " " | " .. | 6 | ·75 | 32·75 | 1864 | 6 | |
| " " | Doulton .. | 9 | ·937 | 64·5 | 3561 | 9 | Pipe well made and burnt. |
| " " | " .. | 9 | ·937 | 62·0 | 2956 | 6 | |
| " " | Pilton .. | 9 | 1·00 | 62·5 | 2470 | 6 | |
| " " | " .. | 9 | 1·00 | 63·5 | 2470 | 5 | |
| " " | " .. | 9 | 1·00 | 64·0 | 2228 | 6 | Badly burnt. |
| " " | Doulton .. | 12 | ·99 | 93·5 | 2834 | 9 | These pipes had a fillet on spigot end. |
| " " | " .. | 12 | ·937 | 92·0 | 2956 | 7 | |
| " " | Pilton .. | 12 | 1·125 | 95·5 | 2470 | 7 | Aylesford pipe, irregular in section and inferior in quality. |
| " " | " .. | 12 | 1·125 | 98·25 | 2350 | 5 | |
| " " | " .. | 12 | 1·187 | 90·5 | 2228 | 7 | |

Socket pipes.

The pipes most generally used in the formation of sewers are ordinary socketed pipes, and when laid in

Fig. 19.



the sewer the spigot end of one pipe is inserted in the socket of another. The spigot end of the pipe should be laid down hill. In the use of socket pipes care should be taken to ascertain that the socket has been made with, and forms a component part of, the pipe. In some cases manufacturers are in the habit of making a distinct pipe, and afterwards working the socket upon it. The consequence is that, not unfrequently, the sockets of pipes so made fail in the work, as such pipes are more fragile than pipes made in one piece. In the laying of sewer pipes it is essential that they should be laid with a perfectly true line of fall from point to point of the sewer, and that each pipe has an uniform bearing throughout its entire length. For this latter purpose a recess should be cut in the floor of every pipe-sewer trench in order to receive the socket, or otherwise each pipe is merely supported from socket to socket. In the early sewer works many failures were traced solely to this cause, the pipes being laid with their sockets on the floors of the trench, the whole load of earth was supported by

Sewer pipes must be truly laid.

Cause of failure of pipes.

the sockets and ends of the pipes, consequently they not unfrequently failed in the work. Great care is also required to be exercised in the jointing of pipes when laid as sewers. The material most commonly used for jointing pipes is clay, which is well adapted under ordinary circumstances for the purpose of preventing the leakage of water from the interior of the pipe, or the water from the earth penetrating the pipe, provided the work is properly performed. In all sewer pipes the sockets are larger or smaller than the spigot end of the pipe. Where clay is used for jointing, a tool should be used for pressing the clay into the socket, and not merely to lay the clay outside the socket, as is done in many cases. After forcing the clay into the socket of the pipe, a fillet of clay should be worked round it to complete the joint. In cases in which much water is found in the subsoil, or where quicksand makes its appearance, it is found necessary to use Portland cement, mixed in the proportion of one part of cement to one of sand, or sometimes two of sand to one of cement.* Whenever cement is used special care must be exercised to see that it does not get into the interior of the pipe. Every pipe should be jointed as it is laid, and no fresh pipe should be laid in position until it has been ascertained that no cement has passed through the joint of the previously laid pipe. The author has seen cases in which drains have been completely stopped, owing to the cement used in jointing having run into the pipes when laid. The best mode of jointing socket pipes, under all circumstances, the author has found to consist in forcing into the socket of every pipe several strands of tarred gaskin, of sufficient diameter to fit the socket tightly. It should be forced into the socket by hand, with a proper caulking tool, and afterwards the joint may be made with clay or cement in the usual way. The advantages of this mode of jointing are obvious. In

Jointing of pipes.

Clay joints.

Cement joints.

Gaskin joints.

Preservation of the annularity of joint.

* Asphalte should be used for jointing sewer pipes when carried under houses.

ordinary sewer pipes there is an annular space between the exterior of the spigot and the interior of the socket of the pipe. When this space is filled with material like clay, and the pipes have not a solid bearing throughout their entire length, the weight of the earth on the pipe, or the effect of men walking over the line of newly-laid pipes after they are jointed, causes the material to be squeezed out of the lower part of the socket, leaving an aperture at the upper part through which sand and water often enter the sewer, and moreover the regularity of the bed of the sewer is in this way often destroyed. Cement joints get cracked and broken in the same way, with the same result, but when tarred gaskin is used the annularity of the joint is maintained, and the material is sufficiently elastic to resile from the effects that destroy other joints; consequently pipes laid and jointed in this manner are found to preserve the uniform and straight lines of fall with which they were laid, and which is an essential feature in every properly-constructed sewer. The tarred gaskin also proves a most effectual agent in preventing the entrance of sand into a sewer through the sockets of the pipes.

Failure of joints.

Prevention of sand entering sewer.

Bothams' pipe.

In order to preserve the concentricity of the joint of pipes when laid, Mr. Bothams, the city surveyor of Salis-

Fig. 20.

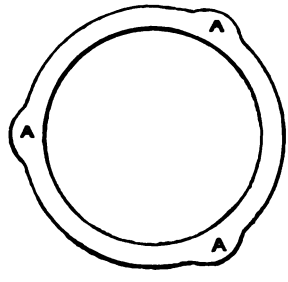
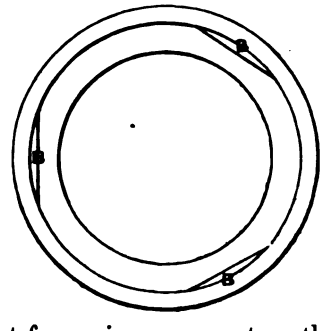



Fig. 21.




bury, has taken out a patent for an improvement on the ordinary socket-pipe, which is illustrated in Figs. 20, 21.

On the spigot end of each pipe projections are formed, as shown by the letter A in Fig. 20; and within the socket corresponding projections are shown, as at B in Fig. 21. The spigot end is inserted in the socket so that its projections lie within the projections in the socket, but on turning the pipe round, the projections of the spigot are brought into contact with the projections of the socket, and so concentricity of the joint is preserved. When pipes are properly bedded throughout their entire length, no precautions are required to preserve the concentricity of the joint, and if not so bedded, other causes of danger arise when the concentricity of the joint is maintained by artificial means, for if not properly bedded, every pipe becomes a girder supported at both ends, and the pipes are liable to failure from the effect of the weight of the superincumbent earth, as was found, in some early sewer works, to be the case, when no recess was cut in the floor of a sewer-pipe trench for the reception of the socket, and when every pipe took its bearing from socket to socket.

Importance of properly bedding pipes.

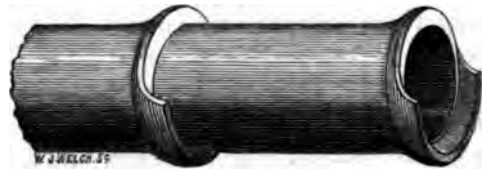
To remove an ordinary pipe from a line of sewer in order to insert a junction, it is necessary to uncover not less than three pipes, and in large sewers a greater number, before a pipe can be raised out of the work. A pipe is usually removed by placing a lever beneath it and springing the line of pipes up, so that they assume an arched form. The pipe in this way is soon liberated from the work; the junction or another pipe may then be inserted by the reverse operation. Care should be taken after performing this work that the foundation below the line of pipes is properly restored, so as to prevent any settlement at the point where the sewer has been disturbed. In the construction of pipe-sewers a number of modifications in the detail of construction have been made by various inventors. One of the first modifications in the form of pipes, as used in the construction of sewers, was to make the pipe with half a socket, as is shown in Fig. 22, the object of this ar-

Removal of pipes from a sewer.

Half-socket pipes.

rangement being to facilitate the removal of any pipe when it became necessary to insert a junction, or for other purposes. Pipes have also been made with half sockets on each end, so that when two pipes are

FIG. 22.



laid together the two half sockets form a whole socket with a joint in the centre of the socket. Pipes have also been made on the Roman type with butt joints, having a loose collar over the joint, forming as it were a double socket joint. This form of joint is still used in cases where earthenware pipes are used to convey water under slight pressure, and they are usually jointed with asphalte. Another form of sewer pipe is shown in Fig. 23.

Collar joint.

FIG. 23.

Jennings' pipe.

This form of pipe was introduced by Mr. George Jennings some years ago. In his description of these pipes he states that they are "plain at both ends, are laid in chairs similar to the metals of a railway, each pipe being kept 6, 9, or 12 inches *apart*, according to their diameter. The pipes being bedded in the chairs renders the disturbance of ground under the pipes to make the joints (as at present) unnecessary, and the top part of the chair (which for distinction is called a saddle-piece) being the last fixed, enables the workman and superintendent to see that the pipes are properly laid and fairly jointed. In case of stoppage the saddle is

easily removed without in any way disturbing the invert or general drain; and the pipes being some distance apart, the state of the drainage can be easily ascertained." Other forms of pipes have been used, such as capped pipes, or pipes in which holes are made in the barrel of the pipe, covered by a cap. Some makers make the opening in the centre of the pipe, others at one end, as is shown in Fig. 24; others again as in Figs. 25 and 26, which represent one of Doulton's opercular pipes.

FIG. 24.

FIG. 26.

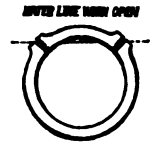
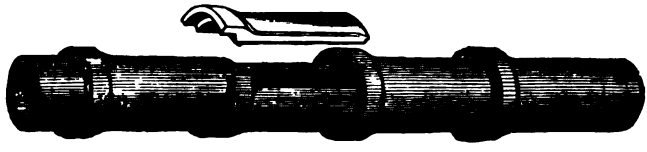


FIG. 25.



The cutting away of the barrel of every sewer pipe for the purpose of rendering it easy of inspection, or to facilitate the work of inserting junctions, to a very great extent interferes with the strength of the pipe, which under some circumstances may lead to their failure in the work. The objection to the use of half-socket pipes, and all those arrangements in which there is a joint about the centre of the pipe, is their liability to leak so soon as they begin to run more than half-full. Since the introduction of the mode of laying sewers in straight lines on plan with manholes or lampholes at changes of inclination or direction, the necessity for the most part has ceased to exist, which brought out all those forms of sewer pipe which were made with a

Objections to some forms of pipe.

special view to facilitate the inspection of the sewers, but which, however good in themselves, multiply the parts, and thereby complicate a work which should be of the simplest character.

Cement pipe.

About the period when earthenware sewer pipes were beginning to be manufactured in this country, pipes were made of Portland cement, but the enormous trade done in the manufacture of stoneware and fire-clay pipes so cheapened their cost, that the manufacturers of cement pipes could not compete with their more fortunate rivals. Pipes made of Portland cement in this country were of the same pattern as those used in the construction of pipes for land drainage, or with both butt and rebated joints. A good Portland cement pipe forms by no means a bad sewer, and it will be a matter for the consideration of the engineer to ascertain if, instead of large pipe sewers, concrete pipes cannot be produced more cheaply, and sufficiently good for the purpose. The author has seen cement pipes that had been in use for twenty years, and they were as sound at the end of that period as when first laid. Cement pipes of large size, with socket-joints, are now extensively used in Germany, and they withstand not only the effects of a severe climate, but the chemical action of the sewage, and are produced at considerably less cost than either a brick sewer or a pipe sewer of equal calibre. Moreover, they show an extraordinary endurance, and remain perfect after severe frost, when brickwork often fails. It is a material that can be worked and moulded into any form, and maintains its form when made. It is also capable of repair, which is a point of no small importance. It is strong, as may be taken from the fact that pipes of this kind are extensively used under the embankments of the North Prussian railways. In a country like Germany, where good earthenware sewer pipes cannot be had unless imported, the use of concrete pipes for large sewers has been extensively introduced. The cement pipes now used in Germany are

Durability of cement pipes.

Cheapness of cement pipes.

Advantages of cement pipes.

Use of cement pipes in Germany.

Form of cement pipe.

made with sockets, and pipes of 12 inches and upwards in diameter are made in lengths of about 5 feet each. The thickness varies with the diameter; pipes of 15 inches and 18 inches diameter, have a thickness of about 2 inches. These pipes improve materially by age, and at the end of a year or two they ring, when struck, with a clear metallic sound. It is necessary to exercise great care in the choice of a cement to be used in the formation of sewer pipes, as some cements are particularly liable to fail from special causes, as will hereafter be pointed out.* The cement pipe manufacturers of Germany fully understand this, and consequently, instead of using the native material, which is of inferior quality, import the best Portland cement from England.

Choice of cement.

In the construction of earthenware pipe and other sewers, where it is possible, trees should be avoided, as their roots will interfere with, and injure the action of, the sewer. The rootlets of trees will extend to considerable depths in search of nutriment or moisture. The author has seen a case in which the fine rootlets of a tree entered the joints of a 15-inch pipe sewer, and, after gaining access to the interior, each of the rootlets developed to such an extent as to completely fill and choke the sewer. Where trees are unavoidable, the work should either be constructed in iron and jointed with lead, or some effectual provision must be made for excluding the roots. A mass of concrete of sufficient thickness placed round the sewer is as effectual a barrier to the roots of trees as can be artificially formed.† Pipe sewers have also occasionally been jointed, when laid near trees, with clay mixed with corrosive sublimate, which is supposed to have the effect of deterring the entry of a living rootlet; but in course of time the poisonous material may be washed out, or may otherwise lose its power, when the sewer is again open to the invasion of an insidious enemy.

Trees to be avoided.

Stoppage of sewers by roots of trees.

Measures to be adopted with trees.

* *Vide* Table 34, p. 137.

† The jointing of earthenware pipes with asphalte will probably prevent the entrance of the roots of trees.

## BRICK SEWERS.

Selection of bricks.

The selection of bricks for the construction of sewers is a matter that requires a considerable degree of attention at the hands of the engineer. The variableness of the quality of bricks throughout the country is only equalled by the diversity of kind which is to be found. For sewer works, specially sound bricks are required, as such bricks are subjected to a variety of forces, all tending to their destruction,—such as sudden changes of temperature, chemical and mechanical action, &c. As a general rule, it may be taken for granted, that bricks of an extremely absorbent character are not well adapted for the construction of sewers. There are, however, exceptions to this rule, in practice, for some very absorbent bricks are extensively used in the construction of sewers, such, for example, as gault bricks. All bricks which are not sufficiently burnt, of whatever description, should be cast aside as totally unfit for sewer work. Bricks used in sewers should have some degree of toughness, and considerable hardness. Perforated bricks are not well adapted for the construction of impermeable sewers, on account of the difficulty of rendering the work water-tight. The best bricks for the construction of sewers, more especially for those parts of the sewer liable to wear and tear from the erosion of the water, and the materials transported over the bed of the sewer, are the blue Staffordshire. Next in order of merit, some of the fire and terra-cotta bricks, and then follow gault bricks. In nearly all parts of the country bricks are found that are well suited for the construction of some part of a sewer, but the bricks above enumerated are undoubtedly the best for inverts and other parts liable to special wear and tear. If there should arise any doubt as to the suitability of a brick for sewer work, it may be tested by first soaking it in

Unburnt bricks should be rejected.

Perforated bricks.

Bricks for the inverts of sewers.

Test for bricks.

water and exposing it to frost; or, should this mode be unavailable, then weigh the brick and steep it for a week in a strong solution of sulphuric acid, weighing it after the test when dry. Another test, equally applicable to brick, stone, mortar, &c., is given in the 'Annales de Chimie et de Physique,' vol. 38, and is as follows:—"Prepare a cold saturated solution of sulphate of soda, then bring it to the boiling point, and suspend in it, by a string, for thirty minutes, the sample under trial; then pour the liquid, free of sediment, into a flat vessel, and suspend the stone over it in a cellar. When efflorescences appear on the specimen, it must be dipped in the solution, say two or three times a day for about a week; at the end of which time the quantity of earthy sediment in the vessel, collected on a filter and weighed, will indicate the effect to be expected from frost on the same sample." If no loss in weight occurs, and the brick in other respects is found to withstand the test, it may be safely used in the construction of sewers. Very soft bricks should on no account be used in the construction of sewers, but the roughness of the face of a brick is no material drawback to its use in the sides of a sewer, provided that there are not any real asperities on the surface that would interfere with the flow, for in all channels a lamina of water adheres to the sides, and the frictional resistance to the flow in consequence is not materially affected by the quality of the material. This, however, would not apply to the invert of a sewer, over which solid matters, such as stones, sand, and other things, are often rolled along. The friction of these matters on the invert of a sewer, constructed of rough bricks, would be considerable, consequently in such cases it is advisable to use glazed bricks, or invert blocks, to form the invert of the sewer. In those districts in which the quality of the bricks is such as to render them, from their character and durability, fit for the construction of certain parts of sewers, though

Soft bricks should be rejected.

Rough bricks.

Friction on invert of sewer.

## TABLE No. 30.—Showing the AMOUNT of ABSORPTION and the STRENGTH of BRICKS.

| No. | Description of Brick. | Where Manufactured. | Name of Maker or Agent. | Size of Brick. Length in Inches. | Breadth in inches. | Thickness in inches. | Weight when Dry. | Weight when Wet. | Amount of Water absorbed. | Percentage of Water absorbed. | Load at which Brick cracked. | Force required to crush Brick. | Force required to crush Brick in tons per sq. inch. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | lbs. | lbs. | lbs. | | lbs. | lbs. | | |
| 1 | Dressed blue brick | Handford, Stafford | S. Glover | 8·90 | 4·37 | 3·05 | 9·213 | 9·503 | 0·290 | 3·147 | 48,944 | 216,944 | 2·490 | |
| 2 | " " " | " " | " " | 8·88 | 4·43 | 2·98 | 9·209 | 9·364 | 0·155 | 1·683 | 54,544 | 230,944 | 2·620 | |
| 3 | " " " | " " | Roe and Son | 9·24 | 4·52 | 2·95 | 9·587 | 9·754 | 0·167 | 1·741 | 9,744 | 312,144 | 3·336 | |
| 4 | " " " | " " | " " | 9·25 | 4·57 | 2·90 | 9·518 | 9·777 | 0·259 | 2·721 | 26,544 | 261,968 | 2·766 | |
| | *Average of dressed blue brick* | | | | | | | | | 2·323 | 34,944 | 255,500 | 2·803 | |
| 5 | Pressed blue brick (with frog) | Handford, Stafford | S. Glover | 8·98 | 4·58 | 2·85 | 8·824 | 8·912 | 0·088 | 0·997 | 57,344 | 144,144 | 1·564 | |
| 6 | " " " | " " | " " | 9·15 | 4·55 | 2·94 | 9·001 | 9·190 | 0·189 | 2·099 | 48,944 | 186,144 | 1·996 | |
| 7 | " " " | " " | Roe and Son | 9·07 | 4·42 | 2·93 | 8·791 | 8·932 | 0·141 | 1·603 | 62,944 | 129,024 | 1·436 | |
| 8 | " " " | " " | " " | 8·90 | 4·50 | 2·85 | 8·760 | 9·155 | 0·395 | 4·509 | 60,144 | 145,824 | 1·625 | |
| 9 | " " " | Longton, Stafford | Prockter and Benbow | 9·30 | 4·55 | 3·00 | 9·288 | 9·888 | 0·600 | 6·459 | 43,344 | 68,544 | ·723 | Brick not entirely crushed. |
| 10 | " " " | " " | " " | 9·22 | 4·63 | 3·20 | 9·790 | 10·251 | 0·461 | 4·708 | 28,224 | 55,664 | ·582 | |
| 11 | " " " | West Bromwich | G. Wood | 8·85 | 4·10 | 2·60 | 7·267 | 7·611 | 0·344 | 4·596 | 70,784 | 406,224 | 4·997 | Brick crushed to powder. |
| 12 | " " " | " " | " " | 9·00 | 4·34 | 2·65 | 7·683 | 8·061 | 0·378 | 4·919 | 14,224 | 172,144 | 1·967 | |
| | *Average of pressed blue brick* | | | | | | | | | 3·736 | 48,244 | 163,464 | 1·861 | |
| 13 | Common blue brick | Handford | S. Glover | 9·45 | 4·28 | 3·02 | 8·504 | 9·066 | 0·562 | 6·608 | 20,944 | 110,544 | 1·220 | |
| 14 | " " " | " " | " " | 9·00 | 4·30 | 3·05 | 8·121 | 8·748 | 0·627 | 7·720 | 26,544 | 85,904 | ·991 | " " |
| 15 | " " " | Longton | Prockter and Benbow | 9·70 | 4·50 | 2·98 | 9·647 | 10·117 | 0·470 | 4·871 | 33,824 | 82,544 | ·844 | |
| 16 | " " " | " " | " " | 9·40 | 4·45 | 3·00 | 9·604 | 10·252 | 0·648 | 6·747 | 34,384 | 71,344 | ·761 | |
| | *Average of common blue brick* | | | | | | | | | 6·486 | 28,924 | 87,584 | 0·954 | |
| 17 | Bastard brick | Longton | Longton Hall Colliery Co. | 9·17 | 4·55 | 3·10 | 9·156 | 10·236 | 1·080 | 11·795 | 51,744 | 79,744 | ·853 | |
| 18 | " " " | " " | " " | 9·30 | 4·62 | 3·33 | 9·837 | 11·004 | 1·167 | 11·863 | 68,544 | 111,664 | 1·160 | |
| | *Average of bastard brick* | | | | | | | | | 11·829 | 60·144 | 95,704 | 1·006 | |
| 19 | Wire-cut white gault brick | Arlsey | Gt. Northern Brick Co. | 9·20 | 4·43 | 2·67 | 6·235 | 7·494 | 1·259 | 20·192 | 15,344 | 103,824 | 1·137 | |
| 20 | " pink " | " " | " " | 9·08 | 4·45 | 2·65 | 6·162 | 7·287 | 1·125 | 18·257 | 15,344 | 132,944 | 1·468 | " " |
| 21 | " white " | Sevenoaks | T. H. Crampton | 8·97 | 4·27 | 2·73 | 5·875 | 7·100 | 1·225 | 20·851 | 32,144 | 118,944 | 1·386 | |
| 22 | " " " | " " | J. R. Heward | 8·93 | 4·17 | 2·85 | 6·404 | 7·493 | 1·089 | 17·004 | 34,944 | 118,944 | 1·426 | |
| | *Average wire-cut white gault brick* | | | | | | | | | 19·076 | 24,444 | 118,664 | 1·354 | |
| 23 | Pressed gault (with frog) | Arlsey | Gt. Northern Brick Co. | 9·00 | 4·40 | 2·77 | 5·814 | 6·938 | 1·124 | 19·332 | 20,944 | 38,864 | ·438 | |
| 24 | Perforated pressed white (with frog) | " " | " " | 8·66 | 4·10 | 2·63 | 5·172 | 6·089 | 0·917 | 17·730 | 11,984 | 87,584 | 1·101 | |
| 25 | " " " | " " | " " | 8·76 | 4·13 | 2·60 | 5·277 | 6·259 | 0·982 | 18·609 | 26,544 | *337,232 | 4·161 | |
| 26 | White pressed gault (with frog) | Sevenoaks | J. R. Heward | 8·97 | 4·44 | 2·64 | 5·973 | 7·081 | 1·108 | 18·550 | 15,344 | 99,344 | 1·113 | |
| 27 | " " " | " " | T. H. Crampton | 9·00 | 4·40 | 2·65 | 6·201 | 7·372 | 1·171 | 18·884 | 40,544 | 102,144 | 1·151 | |
| 28 | Gault machine made " | " " | " " | 8·85 | 4·34 | 2·70 | 5·779 | 7·065 | 1·286 | 22·252 | 16,464 | 90,444 | 1·057 | " " |
| 29 | White gault " | Chilton, Suffolk | | 9·17 | 4·52 | 2·63 | 5·889 | 7·114 | 1·225 | 20·801 | 11,984 | 52,304 | ·563 | " " |
| 30 | Pink gault " | " " | | 9·06 | 4·55 | 2·67 | 6·167 | 7·364 | 1·197 | 19·393 | 16,464 | 66,864 | ·724 | |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Average of pressed grate brick* .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Under | | | |
| 33 | Common red brick .. .. .. | Longton .. .. | T. Newbon .. .. | 9·25 | 4·30 | 3·10 | 8·093 | 8·906 | 0·813 | 10·045 | 4,000 | 50,624 | ·568 | | |
| 34 | " " .. .. .. | " .. .. | " .. .. | 9·08 | 4·28 | 3·05 | 7·945 | 8·759 | 0·814 | 10·204 | 43,344 | 76,944 | ·883 | | |
| 35 | " " .. .. .. | " .. .. | R. Steele .. .. .. | 8·95 | 4·20 | 2·97 | 7·462 | 8·210 | 0·748 | 10·024 | 28,224 | 108,864 | 1·292 | " | " |
| 36 | " " .. .. .. | " .. .. | " .. .. .. | 9·00 | 4·30 | 2·90 | 7·344 | 8·042 | 0·698 | 9·504 | 9,744 | 95,424 | 1·100 | " | " |
| | *Average of common red brick* .. | .. | .. | .. | .. | .. | .. | .. | .. | 9·944 | 21,328 | 82,964 | 0·960 | | |
| 37 | Common stock brick (with frog) | Croydon .. .. | Collis .. .. .. .. | 8·60 | 3·90 | 2·58 | 5·028 | 5·362 | 0·334 | 6·642 | 23,184 | *374,864 | 4·917 | | |
| 38 | Picked " " | Reigate .. .. | Thornton .. .. .. | 9·15 | 4·18 | 2·46 | 4·906 | 5·541 | 0·635 | 12·943 | 24,304 | 135,184 | 1·577 | " | " |
| 39 | " " " | " .. .. | " .. .. .. | 9·00 | 4·15 | 2·62 | 4·933 | 5·674 | 0·741 | 15·021 | 19,824 | *349,776 | 4·180 | | |
| | *Average common stock brick* .. | .. | .. | .. | .. | .. | .. | .. | .. | 11·535 | 22,437 | 286,608 | 3·558 | | |
| 40 | Pressed red brick (with frog).. | Wortley (Leeds) | Ingham and Sons .. | 9·48 | 4·62 | 3·18 | 9·781 | 10·623 | 0·842 | 8·608 | 38,864 | 107,744 | 1·098 | | |
| 41 | " machine made (with frog) .. .. .. .. | * " " | " " .. | 9·34 | 4·45 | 3·44 | 9·823 | 10·747 | 0·924 | 9·406 | 54,544 | 79,744 | ·856 | | |
| 42 | " " " | " " | " " .. | 9·32 | 4·40 | 3·42 | 9·776 | 10·793 | 1·017 | 10·403 | 48,944 | 66,864 | ·727 | | |
| | *Average of machine-made pressed red brick* .. | | .. | .. | .. | .. | .. | .. | .. | 9·904 | 51,744 | 73,304 | ·791 | | |
| 43 | Brown glazed brick (with frog) | Wortley (Leeds) | Ingham and Sons .. | 8·95 | 4·38 | 3·40 | 8·552 | 9·315 | 0·763 | 8·920 | 37,744 | 51,744 | ·589 | | |
| 44 | " " " | " " | " " .. | 9·00 | 4·40 | 3·38 | 8·390 | 9·083 | 0·693 | 8·259 | 34,944 | 50,624 | ·570 | | |
| | *Average of brown glazed brick* | .. | .. | .. | .. | .. | .. | .. | .. | 8·589 | 36,344 | 51,184 | 0·579 | | |
| 45 | White glazed terra-cotta (with frog) .. .. .. .. .. | Wortley (Leeds) | Ingham and Sons .. | 8·80 | 4·38 | 3·15 | 7·511 | 8·259 | 0·748 | 9·958 | 29·904 | 17,144 | ·858 | | |
| 46 | Fire brick, No. 1 .. .. .. | Stourbridge .. | A. Williams, 64, Bankside, S.E. | 9·20 | 4·41 | 2·54 | 7·153 | 7·807 | 0·754 | 10·542 | 60,144 | 104,944 | 1·154 | " | " |
| 47 | " " .. .. .. | " .. | " " | 9·18 | 4·30 | 2·46 | 7·178 | 7·837 | 0·659 | 9·180 | 60,144 | 113,344 | 1·281 | " | " |
| 48 | " ordinary .. .. | " .. | " " | 9·20 | 4·45 | 2·37 | 7·388 | 8·037 | 0·649 | 8·784 | 71,344 | 127,344 | 1·388 | " | " |
| 49 | " " .. .. | " .. | " " | 9·14 | 4·55 | 2·52 | 7·204 | 7·891 | 0·687 | 9·536 | 32,144 | 110 544 | 1·186 | | |
| | *Average of fire brick (Stourbridge)* | .. | .. | .. | .. | .. | .. | .. | .. | 9·510 | 55,944 | 114,044 | 1·252 | | |
| 50 | Furnace brick .. .. .. .. | Leemoor .. .. | Martin .. .. .. | 9·15 | 4·38 | 2·51 | 7·539 | 7·961 | 0·422 | 5·597 | 48,944 | 108,304 | 1·206 | " | " |
| 51 | " .. .. .. .. | " .. .. | " .. .. .. | 9·08 | 4·30 | 2·57 | 7·087 | 7·391 | 0·304 | 4·289 | 15,344 | 137,984 | 1·577 | | |
| | *Average of furnace bricks (Leemoor)* | .. | .. | .. | .. | .. | .. | .. | .. | 4·943 | 32,144 | 123,144 | 1·391 | | |
| 52 | Fire brick .. .. .. .. .. | Newcastle .. .. | A. Williams, 64, Bankside, S.E. | 8·90 | 4·40 | 2·42 | 6·173 | 6·837 | 0·664 | 10·756 | 57,344 | 96,544 | 1·100 | | |
| 53 | " .. .. .. .. .. | " .. .. | " " | 8·93 | 4·40 | 2·45 | 6·120 | 6·675 | 0·555 | 9·068 | 62,944 | 107,744 | 1·222 | | |
| | *Average of fire brick (Newcastle)* | .. | .. | .. | .. | .. | .. | .. | .. | 9·912 | 60,144 | 102,144 | 1·161 | | |
| 54 | Fire brick .. .. .. .. .. | Dinas .. .. .. | .. | 8·92 | 4·25 | 2·50 | 6·353 | 6·953 | 0·600 | 9·444 | 32,144 | 107,744 | 1·268 | | |
| 55 | " .. .. .. .. .. | " .. .. .. | .. | 8·93 | 4·40 | 2·38 | 6·324 | 6·914 | 0·590 | 9·327 | 93,744 | 112,224 | 1·275 | " | " |
| | *Average of fire brick (Dinas)* | .. | .. | .. | .. | .. | .. | .. | .. | 9·385 | 62,944 | 109,984 | 1·271 | | |
| 56 | Fire brick, red .. .. .. .. | Welsh .. .. .. | .. | 8·65 | 4·28 | 2·65 | 6·586 | 6·990 | 0·404 | 6·134 | 18,704 | 99,344 | 1·197 | " | " |
| 57 | " " .. .. .. .. | " .. .. .. | .. | 8·64 | 4·25 | 2·46 | 6·447 | 6·850 | 0·403 | 6·250 | 46,144 | 139,664 | 1·698 | " | " |
| | *Average of red fire brick (Welsh)* | .. | .. | .. | .. | .. | .. | .. | .. | 6·192 | 32,424 | 119,504 | 1·447 | | |

* This brick was considerably compressed before being crushed.

from their roughness they would be ineligible for the invert of a sewer, special bricks or inverts should be used, making use of the local bricks for the construction of the sides and arches of the sewer, and thereby considerably decreasing the cost of the work. The forces principally at work upon a sewer are external, therefore the bricks may be said to be in a state of compression, consequently the only mechanical test to which it is necessary to subject bricks that are to be used in the construction of sewers, is the crushing test. Of course, it is well that they should also be tested for hardness and power of absorbing moisture. Table No. 30 shows a number of experiments made by the author upon various bricks, giving their size, weight, the amount of water they are capable of absorbing, and the crushing force necessary to destroy them.

Forces at work in sewer.

Table 30.

It will be seen, on referring to the foregoing Table, that picked stock bricks are not only less absorbent than gault bricks, but are capable of bearing as great a compressible strain. This is due to the peculiar nature of the material, which is not brittle, therefore it compresses when subjected to great strain. For example, brick No. 37 in the Table had an original thickness of 2·58 inches, but was compressed in the hydraulic press to 1·08 inch in thickness before it failed, and No. 39 in the Table had an original thickness of 2·62 inches, and was compressed to 1·14 inch in thickness. The gault brick that bore the greatest strain, No. 25 in the Table, was likewise compressed from 2·60 inches in thickness to 1·23 inch in thickness before it failed. This degree of compressibility was exceptional with the gault brick, which accounts for the great load borne by this particular brick.

Comparison between stock and gault brick.

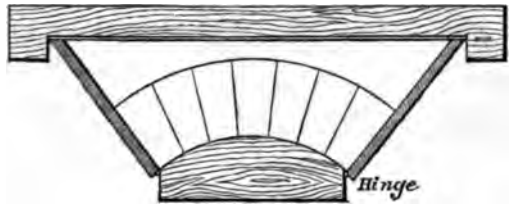
Where bricks are exclusively used in the construction of small sewers, or sewers of oval section, in which the radius of the curve of the invert is small, the sewers should be built up of bricks specially made to the proper radius. Ordinary-shaped bricks are totally inadmissible

Radiating bricks.

for the construction of small brick sewers, on account of the wide gaping joints they leave at the back, as shown in Fig. 6, page 46. In order to secure the greatest uniformity in the sectional form of small sewers, especially their inverts when constructed in brickwork, it is customary to cast the sewer in sections in wooden moulds specially adapted for the purpose. These moulds consist of long troughs, the bottoms of which are made to the true curve of the sewer. The sides of the troughs are hinged and are kept at the proper radius by means of ties placed over the top, as shown in section, Fig. 27.

Brick blocks.

FIG. 27.




The trough is divided by movable boards, which are placed so as to admit of a block 14 inches or 18 inches in length being made, as may be required. The bricks are laid in the troughs, and when the trough, or any one of its divisions, is filled with bricks, cement grout is poured in and fills all the interstices and joints. After the cement has had time to set, the blocks are removed, and each one forms a perfect section of part of the sewer. Sewers should not be entirely built up of blocks, as there is a want of bond in such work; consequently the work is not so strong as a sewer well built up of separate bricks, but brick blocks form a valuable auxiliary, especially in constructing the inverts of sewers in bad ground. Terra-cotta and enamelled bricks have been proposed for lining sewers, but have not hitherto been brought into general use, and as equally durable and serviceable material can be procured at less cost, they are not likely to meet with any considerable demand for this purpose. Invert blocks constructed

Terra-cotta bricks.

Invert blocks.

of terra-cotta, stoneware, or fire-clay, and glazed upon the invert face, are now very generally used in the construction of brick sewers of moderate size. These invert blocks greatly facilitate the construction of the sewer, and from their durability, and the smoothness of their surface, are well adapted for the formation of the invert of sewers. Invert blocks are made with both butt and lipped joints; the latter are preferable, as these blocks are less liable to settle in the work than plain butt-jointed inverts. Fig. 28 shows a bird's-eye view of a lipped invert block.

FIG. 28.

Drainage through invert blocks.

One advantage of these invert blocks is that the continuous opening through the blocks affords a ready mode of getting rid of subsoil water during the construction of the work, which at its completion can be readily stopped without detriment or derangement of the work. The inverts of large sewers should be lined with blue Staffordshire or glazed fire-bricks, or other bricks that are hard, smooth, and adapted for the purpose.

Inverts of large sewers.

Use of templets.

In the building of brick sewers, whether oval, circular, or otherwise shaped, templets should invariably be used, made to the true section of the sewer, in order that the workman may execute the work perfectly true in section. Care must be taken that a sufficient amount of cementing material is used in the work, in order to fill up every interstice and to render the work water-tight,* and also that the cement or mortar used for the purpose is fitted for the particular work. The joints of the work should not exceed one quarter of an inch in thickness,

Cementing material.

Cement joints.

* When a brick sewer is built up in a number of rings it is often advisable in bad ground to make a collar-joint in cement between the rings of brickwork, so as to make the sewer water-tight.

and they should all be stroked with the point of a trowel, which has the effect of increasing the density of the cementing material at the surface, and rendering it less liable to the action of the destructive agents present in a sewer. The arches of the sewer are usually turned upon centres of the proper radius, which are drawn forward as the lower portion of the sewer is executed. A point upon which some stress has been laid by some authorities has reference to the selection of the materials used in the construction of sewers, and the adhesion of the bricks to the cementing material. It is well known that those bricks which are best calculated to resist the erosion and wear and tear of matters conveyed by sewers, are blue Staffordshire bricks, and bricks that have been pressed in the course of manufacture, and yet these bricks have less adhesion between themselves and cement than bricks of an inferior quality. Blue Staffordshire bricks, when laid in cement, can be drawn apart with less force than is required to separate two ordinary stock bricks, the latter bricks being totally unfit for the construction of the invert of a sewer. This want of adhesion between the cementing material and the best of bricks is, however, no particular objection to the use of such materials in a sewer, as it has already been mentioned that the principal strains upon a sewer, and by which it would fail, are not internal but external. In an ordinary cutting the weight of the superincumbent earth is far greater than the internal pressure; consequently, as there is no tendency for the work to be drawn asunder by tensile strains, the non-adhesion of the cement and bricks is no great drawback. There is adhesion enough in any case to maintain the shape and solidity of the work, and to render it water-tight, and the cementing material, if properly compounded, will bear as great crushing strains as the best of bricks.

Arches of sewers.

Adhesion of cement and bricks.

Want of adhesion no objection.

In cases in which much subsoil water occurs, when constructing ordinary brick sewers, it is customary to put in a line of drain-pipes continuously under the

Subsoil drains.

brick sewer in order to convey away the subsoil water, and to give time for the brickwork to set before being exposed to its action. In other cases sump-holes are sunk outside the line of sewer, which are continuously pumped out in order to keep down the subsoil water to a lower level than the brickwork. The great point to bear in mind in the construction of brick sewers in ground surcharged with water, is that the water must not be allowed to come in contact with the brickwork until the mortar has set. If this is not provided for, the soluble parts of the cement will be washed out, and the cement afterwards will never properly set, or will set only in patches, leaving the sewer completely pervious.

Drainage by sump-holes.

Soaking of bricks.

A very important point in the construction of brick sewers is to see that the bricks are perfectly saturated with water before being applied in the work. If this is not done they will rob the cementing material of the moisture necessary for its crystallization and setting, and as a natural consequence the quality of the cementing material will be greatly impaired.

Thickness of brickwork.

In ordinary cuttings of 20 feet, and under, in depth, when executed in good ground, and when the greatest internal dimension of the sewer does not exceed 3 feet, it is customary to build the sewers, whether circular or oval, with a 4½-inch ring of brickwork. Sewers from 3 feet to 6 feet in size are usually built in 9-inch brickwork, and for greater sizes the thickness is increased accordingly. Sewers with straight sides require at least 50 per cent. greater thickness of material than curved sewers of equal dimensions.

Formula for determining thickness of brickwork.

The following formula will be found convenient for determining the proper thickness of the brickwork of sewers.

$$\frac{d\,r}{100} = \text{thickness of brickwork in feet.}$$

$d$ = depth of excavation.

$r$ = external radius of sewer.

Example.

As an example, take a sewer 6 feet internal diameter executed in a 20-feet cutting. It is known from what

has been previously stated, that in practice the brickwork of a sewer of this size should be 9 inches in thickness, therefore the external radius of the sewer would be 3·75 feet, and $\frac{20 \text{ feet} \times 3 \cdot 75}{100} = \cdot 75 \text{ feet} = 9 \text{ inches}$.

For all sizes and depths of sewer, when this formula gives a less thickness than is equally divisable by any number of half bricks of 4½ inches, the proper thickness must be determined, so as to make it fall within and not without the last ring of the brickwork. For example, suppose the formula gave the thickness to be 1 foot, the sewer should be built in three rings of brickwork, or if the thickness given is 15 inches, then the brickwork should be four rings in thickness. The above formula is computed from the safe load that brickwork will sustain, which, in this case, after allowing for any imperfection in the nature and quality of the materials or workmanship, is taken as equal to a column of average earth 100 feet in height.

Basis on which formula is computed.

Sewers have been made in segments of various shapes and materials. Fig. 29 represents a segmental

Segmental sewers.

FIG. 29.

sewer, as manufactured by Messrs. Henry Doulton and Co.

The advantages claimed for this description of sewer are that they are strong, are readily put together, pack closely for transit, and form a perfect and imperishable sewer.

## CONCRETE SEWERS.

When gravel is cheap, concrete should be used.

In districts in which gravel or other suitable material is cheap, good, and easily procurable, the use of concrete in the construction of sewers may be adopted with much advantage, as well as with considerable saving in cost.

Rules for making concrete.

In constructing sewers of concrete the author has generally used a mixture of one part Portland cement, two parts sand, and three parts of stones, broken so as to pass through a 1½-inch sieve turned over on a proper mixing platform, and used fresh in the work. In the Metropolitan district it is customary to use 3 bushels of cement to 1 cube yard of sand and shingle. Where concrete alone is used for the construction of sewers, the bottom part of the sewer is constructed first, and concrete is rammed into position behind the mould of the exact section of the sewer; these moulds are generally covered with sheet zinc, and when in use are greased over so as to render the face of the work as smooth as possible. The upper portion of the work is turned upon centres covered with metal in a manner analogous to that of brick sewers. In some cases the sewers are pargeted with a coat of cement inside.

Moulds for concrete sewer

Fig. 30 represents an oval sewer constructed entirely in concrete. Fig. 31 represents a similar sewer, which is given as an illustration by Mr. John Grant, C.E., as a specimen of Portland cement concrete work, in his paper read before the Institution of Civil Engineers, in

April, 1871. It represents a section of a sewer constructed in the Earl of Deptford Lower Road. The author states, with regard to this sewer, that it is "7 feet 1 inch in diameter, cost per lineal foot, irrespective of earthwork, 16*s.*; but, inclusive of earthwork, side entrances, junctions, &c., it was about 23*s.* per lineal foot. This sewer was in some respects exceptional, inasmuch as it consisted of little more than an arch over a previously existing invert; the lower half was, however, rendered with

FIG. 30.

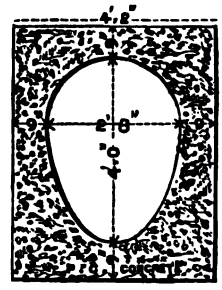
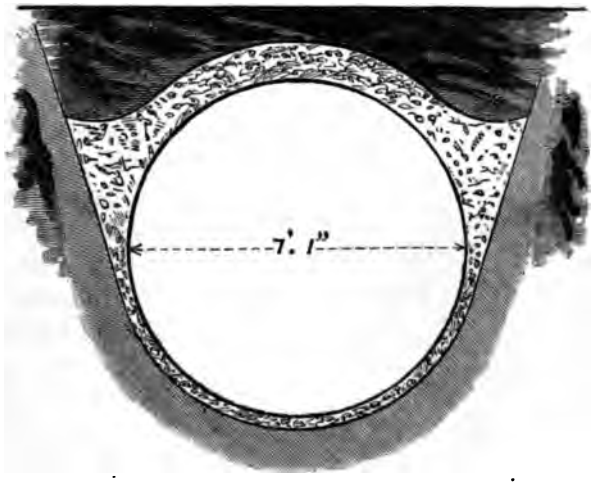


FIG. 31.




cement and sand in equal proportions, 1 inch thick." In the construction of sewers entirely of concrete it is necessary to have a much longer length of trench opened in the streets than is requisite for brick sewers, in order to allow the work to set completely before the trenches are filled in; moreover, special means must be taken during construction to prevent the collapse of the sewer before the work is perfectly solidified. The

Extra length of sewer trench open.

Centres: when they are to be removed.

centres of any particular length should not be removed until the work is set. Concrete sewers may be constructed of bricks made of concrete, and built up as ordinary brick sewers, but in this form they become more expensive than brick sewers. They may also be constructed of blocks cast in moulds, similar to brick blocks described in Fig. 27, page 125, which are afterwards built up in the sewer. The author has built some considerable lengths of sewer in concrete blocks, using a key of brickwork in the arch. Probably the most economical and best form in which concrete can be used in the construction of large sewers is when used in combination with brickwork. Combined concrete and brick sewers may be constructed with perfect safety of any dimensions; the brickwork in this case forms, as it were, a centre for the concrete, and owing to the smaller amount of labour required, this form of construction is not so expensive as an entire concrete sewer, yet it is far cheaper and stronger than an entirely brick sewer. Fig. 32 represents a section of the Croydon outfall sewer, 4 feet internal diameter, constructed with an inner ring of brickwork, the outer portion of the sewer being formed of concrete. This sewer was constructed above the level of the ground, and for some months was running full bore without any earth backing at the sides, and yet, though containing such a small amount of material, not the slightest leakage took place. This was a test that no ordinary brick sewer could have borne under such circumstances, showing at once that there is a considerable degree of tenacity in the concrete covering. Fig. 33 shows a section of a sewer as constructed by the Metropolitan

Concrete bricks.

Concrete blocks.

Combined concrete and brick sewers.

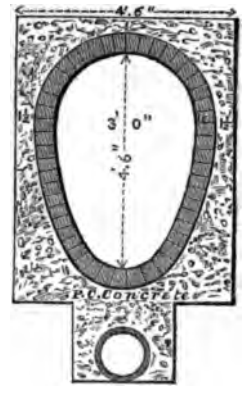
Croydon outfall sewer.

FIG. 32.

Test of combined concrete sewer.

Board of Works, partly in brick and partly in concrete; the section also shows a pipe laid in the concrete below the level of the sewer for drainage purposes. In the making of concrete special care must be exercised with regard to the selection of the materials, especially that the cement is of good quality, capable of withstanding both the chemical and mechanical tests which it ought invariably to be subjected to before being used in sewer work, as will hereafter be considered.* The stone or gravel used in the making of concrete should be thoroughly saturated with water, for if dry it will have a tendency to abstract water from the cement, and interfere with its setting properties.

FIG. 33.




Importance of good materials.

Stone should be saturated.

The following Tables give the relative tensile and compressive strength of Portland cement concrete.

TABLE No. 31.—Showing the TENSILE STRENGTH of CONCRETE after 12 months, made with PORTLAND CEMENT weighing 112 lbs. per bushel. Compiled from experiments by J. GRANT, Esq., C.E.

Table showing tensile strength of concrete.

| Proportion of Tensile Strength. | |
|---|---|
| Ballast to Cement. | In lbs. per sq. in. |
| 3 to 1 | 240·44 |
| 4 „ 1 | 246·22 |
| 5 „ 1 | 214·22 |
| 6 „ 1 | 141·77† |
| 7 „ 1 | 163·33 |
| 8 „ 1 | 156·42 |

* *Vide* pages 134 to 137.

† There appears to have been a flaw in this specimen.

Table showing compressive strength of concrete.

TABLE No. 32.—Showing the CRUSHING STRAIN on BLOCKS of CONCRETE 6 in. × 6 in. × 6 in., made with PORTLAND CEMENT weighing 110·56 lbs. per bushel, and when compressed and not compressed, and when set in AIR and WATER, after 12 months. Compiled from experiments by J. GRANT, Esq., C.E.

| Proportion of Ballast to Cement. | Compressed Blocks. | | Not Compressed Blocks. | |
|---|---|---|---|---|
| | Set in Air. | Set in Water. | Set in Air. | Set in Water. |
| | tons per in. | tons per in. | tons per in. | tons per in. |
| 1 to 1 | 1·055 | ·933 | ·833 | 1·041 |
| 2 „ 1 | 1·194 | ·958 | 1·069 | 1·000 |
| 3 „ 1 | ·833 | ·986 | ·666 | ·777 |
| 4 „ 1 | ·833 | ·777 | ·777 | ·750 |
| 5 „ 1 | ·680 | ·986 | ·666 | ·652 |
| 6 „ 1 | ·566 | ·544 | ·505 | ·472 |
| 6 „ 1 | ·458 | ·444 | ·388 | ·347 |
| 8 „ 1 | ·375 | ·375 | ·347 | ·305 |
| 9 „ 1 | ·333 | ·305 | ·277 | ·250 |
| 10 „ 1 | ·291 | ·291 | ·222 | ·194 |

## CEMENT AND MORTAR.

Failure of works from selection of unsuitable materials.

The selection of proper cementing material for the construction of sewers is one of vital importance to the stability of the work. In many cases in this country sewers have failed from the injudicious use of a cementing material totally unsuited for the purpose to which it was applied. The author has seen cases in which, either from the want of sufficient experience on the part of the persons employed in designing the works, or with a view of saving some trifling sum in the first cost, a cementing material has been selected for the construction of sewers totally unfit to resist the chemical action of the sewage, and the consequence has been that such sewers have failed. The cementing material used in the imperfect work here mentioned consisted of ordinary chalk lime mortar, or of chalk lime mortar mixed with a small percentage of Roman cement. The chemical action of sewage upon such mortar is due

Effect of sewage on chalk lime.

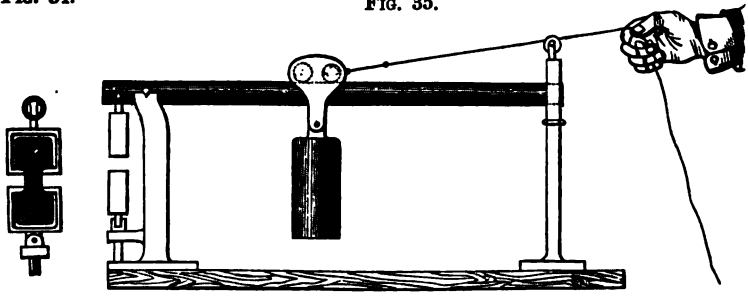
to the presence of ammonia, which, when brought into contact with ordinary lime, is converted by oxidation either into nitrous or nitric acid, which acids readily combine with the lime, and when they have so combined form nitrates or nitrites of lime, which salts are extremely soluble; the lime in this new form is soon washed out of the joints of the brickwork by the flow of the sewage through the sewer, or by subsoil water infiltrating through the work into the sewer, and every particle of lime may be carried away, leaving nothing but the sand to hold the sewer together; consequently, as the work is no longer capable of bearing any strain upon it, such sewers either entirely collapse, or become so distorted in shape as to be unfit for the purposes for which they were intended. The adoption therefore of a durable cementing material for the construction of sewers is a point of the first importance, and too great care cannot be exercised in the selection of proper materials. Where doubts exist as to the behaviour of cements or limes when brought into contact with sewage, it will be well to subject them both to a chemical and mechanical test, in order to ascertain if they are fit for the purposes for which they are intended. Mechanical tests for limes and cement consist in moulding the material into blocks of the shape shown in Fig. 34,

Chemical and mechanical tests should be applied.

Mechanical tests.

Fig. 34.

Fig. 35.



which, after being set in a proper mould, is taken out and allowed to remain under water for a period of

seven days, and then placed in clips shown in the foregoing figure and transferred to the breaking machine, as illustrated in Fig. 35. Cements differ materially in their power to resist tensile strains, as will be seen from the following Table, No. 33:—

TABLE No. 33.—Showing the RELATIVE TENSILE STRENGTH of PORTLAND, ROMAN, and MEDINA CEMENTS. Compiled from experiments by J. GRANT, Esq., C.E.

| Age. | Portland. 123 lbs. per bushel | White Brothers' Roman. | Medina. |
|---|---|---|---|
| | lbs. per in. | lbs. per in. | lbs. per in. |
| 7 days .. .. | 363·15 | 89·77 | 40·93 |
| 1 month .. .. | 415·91 | 115·68 | 131·55 |
| 3 months .. .. | 469·28 | 143·33 | 199·46 |
| 6 „ .. .. | 522·93 | 210·08 | 183·28 |
| 9 „ .. .. | 541·77 | 209·33 | 203·20 |
| 12 „ .. .. | 546·53 | 285·82 | 211·95 |
| 2 years .. .. | 588·84 | 242·66 | 122·66 |
| 3 „ .. .. | 584·17 | 268·35 | 122·48 |
| 4 „ .. .. | 583·37 | 280·97 | 127·91 |
| 5 „ .. .. | 576·00 | 278·66 | 140·88 |
| 6 „ .. .. | 581·33 | 296·17 | 162·22 |
| 7 „ .. .. | 589·95 | 314·97 | — |

Strongest cement cheapest.

It should be here noted that a cement capable of bearing great tensile and crushing strains when more expensive in first cost, is often cheaper to use than an inferior cement, as it is capable of being mixed with a large percentage of sand, producing more cementing material of a quality equal to that made with a cheaper cement. The material which has the greatest power to resist the action of acids, and is the strongest, is undoubtedly the best for sewer purposes. The

Chemical test for cement.

chemical action of sewage upon an untried cementing material may be arrived at by subjecting it to a standard solution of nitric acid. The following Table, No. 34, shows the results as arrived at by the author with regard to the resisting power of various cements to the action of nitric acid. Each of the samples tested was made in a mould of the same size, and was submerged for ten days in a solution of distilled water containing ten per cent. of nitric acid.

TABLE No. 34.—TESTING of various kinds of LIME and CEMENT to RESIST the ACTION of NITRIC ACID. The specimens were exposed for ten days in a solution containing 10 per cent. Nitric Acid.

Nitric acid tests of cements.

| Description of Material. | Whether set in Air or Water. | Weight in grains before Chemical Test. | Weight in grains after Chemical Test. | Loss in grains. | Per-centage of Loss. | Remarks. |
|---|---|---|---|---|---|---|
| Croydon chalk lime | Air | 792 | 225 | 567 | 71·5 | |
| Ditto .. .. .. | Water | .. | .. | .. | .. | Would not set in water. |
| Ditto and sand .. | Air | 1410 | 68 | 1342 | 95·1 | |
| Ditto .. .. .. | Water | .. | .. | .. | .. | " " |
| Dorking lime .. | Air | 884 | 601 | 283 | 32·0 | |
| Ditto .. .. .. | Water | 957 | 616 | 341 | 35·6 | |
| Ditto and sand .. | Air | 1405 | 710 | 695 | 49·4 | |
| Ditto .. .. .. | Water | 1211 | 722 | 489 | 40·3 | |
| Blue lias .. .. | Air | 989 | 759 | 230 | 23·2 | |
| Ditto .. .. .. | Water | 1077 | 891 | 186 | 17·2 | |
| Ditto and sand .. | Air | 1207 | 795 | 412 | 34·1 | |
| Ditto .. .. .. | Water | 1129 | 856 | 273 | 24·1 | |
| Barrow lime .. .. | Air | 1091 | 705 | 386 | 35·3 | |
| Ditto .. .. .. | Water | 1044 | 776 | 268 | 25·6 | |
| Ditto and sand .. | Air | 1256 | 610 | 646 | 51·4 | |
| Ditto .. .. .. | Water | 1217 | 781 | 436 | 35·8 | |
| Plaster of Paris .. | Air | 1314 | 1269 | ·45 | 3·4 | |
| Ditto .. .. .. | Water | 1402 | 1462 | .. | .. | Increased in weight by contact with acid. |
| Ditto and sand .. | Air | 1396 | 1272 | 122 | 8·7 | |
| Ditto .. .. .. | Water | 1436 | 1306 | 130 | 9·0 | |
| Keene's cement .. | Air | 1262 | 1246 | 16 | 1·2 | |
| Ditto .. .. .. | Water | 1269 | 1255 | 14 | 1·1 | |
| Ditto and sand .. | Air | 1452 | 1026 | 426 | 29·3 | |
| Ditto .. .. .. | Water | 1565 | 734 | 831 | 53·0 | |
| Portland cement .. | Air | 1242 | 1189 | 53 | 4·2 | |
| Ditto .. .. .. | Water | 1345 | 1284 | 61 | 4·5 | |
| Ditto and sand .. | Air | 1470 | 1400 | 70 | 4·7 | |
| Ditto .. .. .. | Water | 1293 | 1146 | 147 | 11·3 | |
| Roman cement .. | Air | 1289 | 1243 | 46 | 3·5 | |
| Ditto .. .. .. | Water | 1272 | 1225 | 47 | 3·6 | |
| Ditto and sand .. | Air | 1430 | 1286 | 44 | 3·0 | |
| Ditto .. .. .. | Water | 1378 | 1267 | 111 | 8·0 | |
| Medina cement .. | Air | 1313 | 1148 | 165 | 12·5 | |
| Ditto .. .. .. | Water | 1325 | 1130 | 195 | 14·7 | |
| Ditto and sand .. | Air | 1445 | 1252 | 193 | 13·3 | |
| Ditto .. .. .. | Water | 1420 | 1205 | 215 | 15·1 | |

NOTE.—When sand was used in the foregoing experiments it was mixed in equal volume with the lime or cement.

A most valuable and elaborate series of experiments on the strength of cement have been carried out by Mr. John Grant, C.E., and these experiments have had a material influence on the improvement of the manufacture of Portland cement. The results that Mr. Grant

Mr. J. Grant's experiments.

arrived at with regard to cement are recorded in two papers read before the Institution of Civil Engineers in 1866 and 1871, and may be referred to with advantage by all persons seeking information upon this very important subject. Portland cement is by far the best material that can ordinarily be used in the construction of sewers. It is an artificial cement composed of chalk and clay burnt at a high temperature, and is then ground to fine powder; the finer it is ground the better it is. The strength of Portland cement depends very much upon its weight; the heavier the cement, the stronger it is, but the heavy cements require a longer period to arrive at their ultimate strength than lighter cements, and the strongest cements are the longest in setting, showing how necessary it is that provision should be made in the construction of sewers to protect the cement from being exposed to the injuries arising from the presence of subsoil water during the construction of the work. Smeaton used plaster of Paris to protect the joints of masonry from the action of the sea, and Roman cement has been used for like purposes to protect a slower-setting but stronger cement. Good Portland cement should not weigh less than 110 lbs. per striked bushel,* and should be capable of bearing a tensile strain of 350 lbs. to the square inch, after seven days immersion in water. It should be ground sufficiently fine to pass through a sieve having 1600 meshes to the square inch. Portland cement has the valuable property of not deteriorating by age, provided it be kept dry; on the contrary, a certain amount of age improves its quality. The amount of cement that should be used in making mortar, which is the material used to combine together the bricks so as to form one mass, will be a matter of judgment for the engineer. Under no circumstances, however, should the amount of cement be less than the interstitial space of the sand which is to be used, if a really uniform and homogeneous com-

Portland cement.

Protection of cement from flowing water.

Qualities of Portland cement.

Admixture of cement and sand.

* The cement should be filled into the measure from a hopper.

pound is to be the result. The interstitial space of the sand may be arrived at by the amount of water it is capable of absorbing, which will represent the interstitial space. It may be taken for granted that the mixture of any quantity of sand with Portland cement materially affects its strength, both tensile and compressive, as will be seen from the following Tables:—

Mode of finding interstitial space.

TABLE No. 35.—Showing the TENSILE STRENGTH of neat PORTLAND CEMENT weighing 112 lbs. the striked bushel, also when mixed with a certain proportion of Thames sand. Compiled from experiments by J. GRANT, Esq., C.E.

Tensile strength of cement and sand.

| Age. | Neat Cement. | Proportion, 1 to 1. | Proportion, 1 to 2. | Proportion, 1 to 3. | Proportion, 1 to 4. | Proportion, 1 to 5. |
|---|---|---|---|---|---|---|
| | lbs. per in. | lbs. per in. | lbs. per in. | lbs. per in. | lbs. per in. | lbs. per in. |
| 1 month | 348·66 | 166·00 | 100·31 | 48·00 | 40·22 | 19·11 |
| 6 months | 426·66 | 268·08 | 178·08 | 136·94 | 66·22 | 54·80 |
| 12 „ | 448·80 | 321·76 | 214·84 | 164·94 | 88·08 | 90·84 |

TABLE No. 36.—Showing the CRUSHING STRAIN of BRICKS 9 in. × 4½ in. × 3 in., made from PORTLAND CEMENT weighing 110·56 lbs. per Bushel, when compressed and not compressed, and when set in AIR and WATER, after 12 months. Compiled from experiments by J. GRANT, Esq., C.E.

Compressive strength of Portland cement and sand.

| Proportion of Cement and Sand. | Compressed. | | Not Compressed. | |
|---|---|---|---|---|
| | Set in Air. | Set in Water. | Set in Air. | Set in Water. |
| | tons per sq. in. | tons per sq. in. | tons per sq. in. | tons per sq. in. |
| Neat | 2·360 | 3·274 | 2·776 | 2·811 |
| 1 to 1 | 2·044 | 2·057 | 1·561 | 1·549 |
| 1 „ 2 | 1·728 | 1·410 | 1·024 | ·972 |
| 1 „ 3 | 1·328 | ·656 | ·656 | ·538 |
| 1 „ 4 | 1·076 | ·738 | ·489 | ·338 |
| 1 „ 5 | ·923 | ·372 | ·377 | ·212 |
| 1 „ 6 | ·747 | ·277 | ·271 | ·142 |
| 1 „ 7 | ·713 | ·260 | ·211 | ·105 |
| 1 „ 8 | ·475 | ·201 | ·174 | ·057 |
| 1 „ 9 | ·432 | ·183 | ·131 | ·057 |
| 1 „ 10 | ·381 | ·138 | ·118 | ·056 |

General Scott has invented a process, and brought into operation a system of manufacturing Portland cement and selenic mortar, in combination with the clarification of sewage,* which will be hereafter considered.

General Scott's Portland cement manufactured from sewage.

* This process is explained in another volume of 'Sanitary Engineering,' under head of Lime processes of purifying sewage.

Roman cement.

Roman cement was formerly largely used in the construction of sewers, both by itself and also in combination with lime mortars. It is not more than two-thirds the price of Portland cement, but it is not more than one-third as strong, so that, for all general purposes, Portland cement is the cheapest material, and is otherwise preferable.

Sets quickly.

Roman cement has the power of setting quicker than Portland cement, and on the other hand, if it is exposed to air, it absorbs moisture and carbonic acid, which form silicates and aluminates of lime, and destroy the quality of the cement. It is not capable of bearing a greater tensile strain than from 100 lbs. to 125 lbs. the square inch, after seven days' immersion.

Strength of Roman cement.

Manufactured from Septaria.

It is manufactured from Septaria, found in the London clay and other geological formations. Roman cement is best when light, and should not weigh more than 75 lbs. per striked bushel, nor should it be used with a greater proportion of sand than one to one. It is occasionally used to protect the joints of slow-setting cements, and on account of its quickly setting is often a valuable agent in some special works.

Weight of Roman cement.

Medina cement.

Medina cement is a variety of Roman cement containing a rather larger percentage of lime, and is made from Septaria procured from Hampshire. It has the power of setting rapidly, but is inferior to Portland and Roman cements in point of strength. In some cases, hydraulic limes, such as some of the Blue Lias limes, may be used with advantage in sewer and water works, but, on account of their variable quality, in no case should they be adopted in the construction of a sewer until it has been shown that they are able to withstand the chemical action of the sewage, as well as possessing the mechanical advantage of strength. Many of the Lias limes are apt to cause rupture of the work if not finely ground, therefore, when limes of this class are used for sewer work, they should invariably be tested by being sifted, and all samples not ground sufficiently

Strength of Medina cement.

Lias limes.

fine to pass the sieve,* as used in testing Portland cement, should be rejected. Many other cements, such as Keene's Parian, plaster of Paris, and others, are all fitted for the construction of sanitary works, but are more especially adapted for the interior fittings of public and private buildings. In using all cements care should be taken that no more is mixed at one time than will be quickly used, for any cement that sets or becomes hard is unfit for use, and should be rejected.

Necessity for fine grinding.

Keene's Parian and plaster of Paris.

Cement that has set to be rejected

## SAND AND WATER.

An important point in the selection of materials is to procure a pure silicious sand for mixing with cement or lime to form mortar. The sand used should be free from all nitrogenous, and some saline matters, such as alkaline chlorides; if not, these matters are liable to undergo a chemical change, after being mixed with the lime and cement, and so cause a rupture of the work even after it has set. For cementing purposes, for mixing with cement, a sharp sand is undoubtedly the best. It would be a saving of cementing material to select sands of various degrees of fineness, so as to reduce the interstitial space as much as possible. Pure silicious sand forms, in combination with the limes, a silicate of lime which augments the strength, especially in those parts excluded from the air, as the interior of thick walls. Sand acts as a dilutant for cement, so that its approximate strength, within certain limits, may be arrived at by knowing the proportions of sand used.

Influence of nitrogenous and saline matters.

Sharp sand best.

Silicious sand.

Sand a dilutant.

With regard to the selection of water, either fresh or sea water may be used for mixing with Portland cement.

Water.

* Sieve having 1600 meshes to the square inch.

Sea-water.

It has been shown by Mr. J. Grant, C.E., that the use of sea-water augments the strength of Portland cement. This may be due to certain combinations taking place between some of the salts in sea-water and the cement; on the other hand, the excess of certain salts will undoubtedly injure the cement. Sewage-water, for example, should on no account be used in compounding mortar. The author has seen cases in which the best materials, both as regards cement and sand, have been used, but when mixed with sewage water the cement has never properly set, while the same cement, in the same work, compounded with pure water, has set rapidly and well. Care should also be taken in the mixing of cement that too great a proportion of water is not used. The smaller the quantity of water used in the compounding of cement the better it will be found to be. The volume of water to be used, therefore, should only be sufficient to bring the mortar into a thick paste. Where more water is requisite, it is a sign that the bricks or other materials which are used in the construction of the works have not been sufficiently soaked, and that the mortar is robbed of its moisture, by reason of the inattention paid to this important point.

Excess of certain salts injurious.

Too much water injurious.

## TIMBER.

Use of timber.

In all works of sewerage timber is extensively used in all the preliminary operations, either for shoring the trenches, shafts, or tunnels; or for constructing centres, templets, trunks, or shoots for the discharge of water. It is also occasionally used permanently in works of sewerage, as in forming foundations, or for the protection of work in exposed situations, or as a casing for a

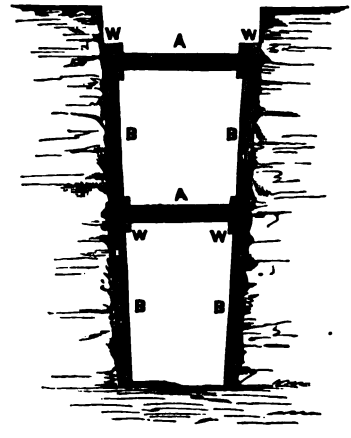
protection against frost, or to guard some outfall works from injury, such as they are liable to incur when it is necessary to pass outfall sewers along the sea-shore or into navigable channels. The outfalls of sewers into the sea, or into a tidal estuary, are usually marked by timber piling, to protect them against displacement by vessels, and which also serve as a beacon to mark the point of outfall, thus warning vessels from approaching too near. In all temporary works it is customary to select the cheapest timber at hand. Both English and foreign-grown timber of every variety is extensively used in shoring trenches. In some cases special timber, such as oak, is used, where great strength is required, as in some tunnel work. Fig. 36 represents one of the simplest modes adopted for shoring trenches for sewer and other works. The trench is cut slightly tapering, being wider at the top than at the bottom, as there is a tendency for the timber to tighten, if it slips, or the earth contracts from drying. This system consists in providing horizontal walings, W, which are kept in position by struts, A. The walings are often supported by props, B, which are put under them, and serve to keep them in position, so that if any settlement takes place the whole framing will subside together. In other cases walings are used with short boards at the back, called poling boards, which are usually 1½ in. in thickness, and their object is to shore a larger side area of the trench than is the case when walings alone are used. This system is illustrated in Fig. 37.

Sea works.

Selection of timber.

Shoring trenches.

Fig. 36.




Poling boards.

Fig. 38 represents a mode of shoring trenches in bad

Trenches in bad ground.

ground. In this case the walings and struts are used as before, but instead of poling boards the runners, R, are

Fig. 37.

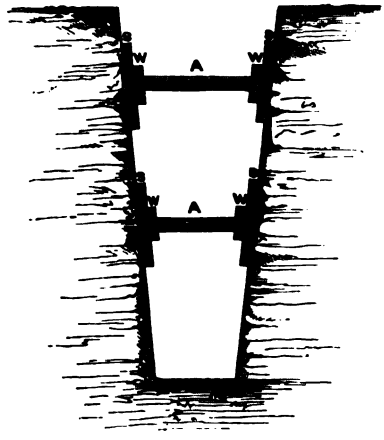
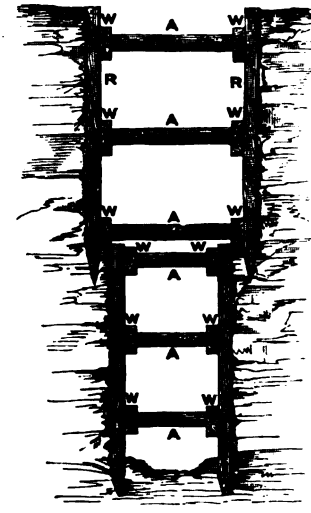



Fig. 38.




used, and they are sharpened at the bottom and driven as sheet piling behind the walings. The trench in this system, in the first place, must be excavated sufficiently wide at the top to enable as many tiers of runners to be used as may be requisite to get the proper width of trench at the depth required. It should be observed, in timbering trenches, that the timber should be wedged up tightly against the sides of the trench, in order to prevent the slightest chance of movement in the surrounding earth, but not so tightly as to disturb the earth.

Struts. The struts, as a rule, should be of as great a diameter as possible, for if they are small in diameter, in proportion to the width of the walings, they are apt to split the walings if any great strain is brought upon them. Where half-round timbers are used for shoring purposes, the flat sides of the timber should be placed against the side of the trench. The struts in this case should be cut to fit the walings, or, as it is termed, should be "bird's-mouthed" at the end to fit the

rounded side of the walings. In bad ground, and when the trenches are closely timbered, it is customary to use litter, ashes, and other suitable materials for packing behind the poling boards or runners, so as to prevent the entrance of quicksand and water into the excavation. Owing to the great amount of waste that usually takes place in the use of timber in trenches, several devices have been introduced to prevent the breakage of the material, and to render it of use more than once. With this view Mr. Kirkman introduced a screw at one end of the strut, which he calculates, in a work of any considerable extent, not only saves trouble, but will pay for its expense. In trenches of large size whole baulks of timber are required to be used, in which case they are tightened up by wedges, and such timbers require to be supported and braced in all directions. In tunnel work, material of good quality should be selected for timbering, and such timber should be hard and tough, as at unknown times and places considerable strains are liable to be thrown upon it. In ordinary tunnelling for sewer work the sills and posts are made of fir, and the side posts are usually placed at an angle, and mortised or notched into the sills. The poling boards or staves are usually driven diverging outwards, so that one set overlaps the

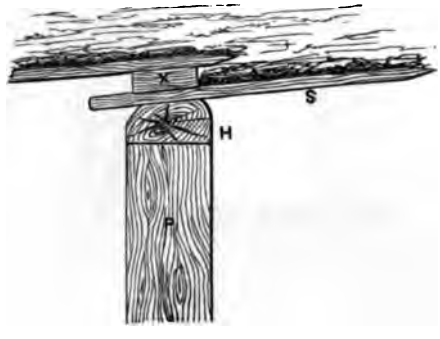
Packing against quicksand.

Devices to economize timber.

Large trenches.

Timber for tunnels.

FIG. 39.



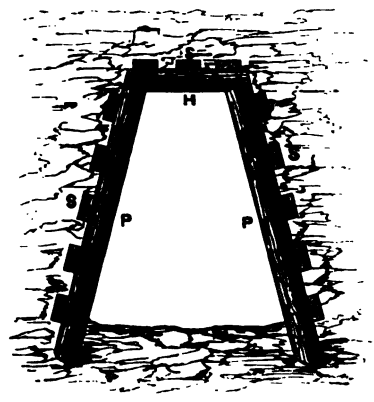

preceding set, with a wedge between the two, as shown in Fig. 39. S shows the position of the staves or poling

boards, H the head of the framing, P side post of framing, and X the wedge for keeping the staves in position.

Tunnelling in good ground.

When tunnelling in good ground, the side posts may be sunk into the bottom of the excavation for a few inches, and poling boards or staves are placed at the back of the framing, as shown in Fig. 40.

FIG. 40.

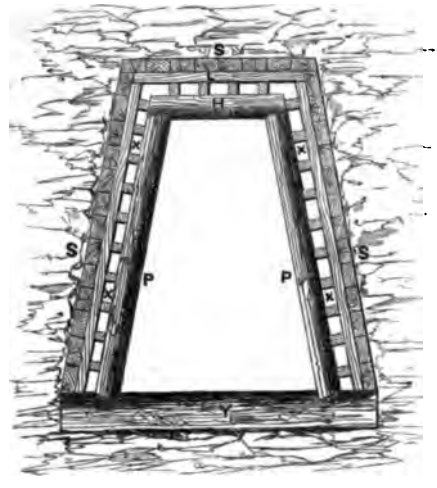



Tunnelling in bad ground.

When tunnelling in bad or unstable ground, a section of framing similar to that in Fig. 41 is usually adopted.

It consists in closely timbering the tunnel with the

FIG. 41.




staves or poling boards S, the staves, being kept in position by the framing L, which forms a lintel and side frame in addition to the ordinary framing, and the

wedges for setting up the work are inserted between the two sets of framing.

The floor of the tunnel may be treated in a similar manner to the head, or it may be covered with planks spiked down to the sills of the framing. In all cases, whether in tunnelling or open trench work, where the ground is unstable, or where slips of earth are likely to take place, which may damage either the works executed, or any adjoining property, it is customary to leave in the timber in order to take the strain until the trench has become completely consolidated, which in some cases may not occur for a course of years. In carrying out sewer works in narrow streets, it is advisable to shore the houses, and the stays introduced should be removed with caution, but not until the excavation is properly consolidated.

Timber should be left in.

Shoring in narrow streets.

Timber has been extensively used in past ages for the formation of aqueducts for conveying water, and for the construction of water-pipes, but for these purposes it has now been generally superseded by iron. Its use for such like purposes has, however, again been revived, as it has been proposed to construct circular channels of wooden laggings, bound together with wrought-iron hoops barrel, fashion, and supported on piers, for the purpose of conveying and distributing sewage over land. Timber is also now occasionally used for the construction of movable carriers for distributing sewage on land, and is largely used for the construction of sluice frames and doors on all sewage irrigation works.

Timber, pipes, &c.

The best descriptions of timber to be used permanently in sewer or water-works, and in all situations where it is liable to be affected by dampness, are alder, beech, elm, larch, oak, and teak. In the selection of timber to be used permanently in sanitary works, care should be exercised that it is free from injurious shakes, large and loose knots and sap-wood. Various processes have been adopted in order to protect timber from

Descriptions of timber best adapted.

Protection of timber.

premature decay, and from the attacks of certain species of fungi and insects, which in some situations are liable to prey upon it, and so cause its rapid destruction. The systems are known as Kyanizing, Burnettizing, Bethell's, and Payne's processes.

Kyanizing. Kyanizing consists in saturating the timber in a solution of corrosive sublimate (bichloride of mercury). The quantity of bichloride to be used depends more or less upon the porosity of the timber; it varies from 1 lb. to every 10 gallons for a strong solution, to $\frac{3}{4}$ lb. for a weak solution, the timber being exposed in tanks, so constructed that no metal is brought into contact with the solution for a period varying according to the thickness of the timber, twenty-four hours of exposure being allowed for each inch in thickness of the material.

Burnettizing. In Burnettizing a solution of chloride of zinc in combination with water is used, $2\frac{1}{2}$ lbs. of chloride of zinc being used for every 10 gallons of water.

Bethell's process. Bethell's process consists of impregnating the timber with creosote; the timber for this purpose is exposed in tanks, properly constructed, for a sufficient time to ensure saturation.

Payne's process. Payne's process consists in first saturating the timber with a solution of sulphate of iron, and afterwards treating it with a solution of some of the alkaline carbonates, which have the effect of decomposing the sulphate of iron and producing within the interstices of the timber an insoluble oxide of iron.

Charring timber. Timber is also occasionally protected in some situations by being charred or burnt on the exterior surface, the exposed charcoal surface being less liable to decay than the natural timber.

Pigments. Pigments of various descriptions, having for their basis the oxides of lead, iron, or zinc, are universally used to protect timber from the weather. Tar, pitch, and its compounds are also extensively used, and are very efficient for the protection of timber in works of sewerage.

Strength of timber. The strength of timber when used in sewer or other

work may be arrived at by reference to the following Table, which shows the tensile and compressive strength of various kinds of timber; also the value of the coefficients E and S as used in the formula of Professor Barlow in arriving at the strength and deflection of timber girders and other structures.

TABLE No. 37.

Table of strength of timber.

| Description of Timber. | Specific Gravity. | Tensile Strength. | Compressive Strength. | Reduced Value of E. | Value of S. |
|---|---|---|---|---|---|
| | | lbs. per sq. in. | lbs. per sq. in. | | |
| Teak .. .. .. | ·745 | 8,000 | 12,000 | 349 | 2110 |
| English oak .. | ·934 | 19,000 | 10,000 | 209 | 1672 |
| Canadian oak .. | ·872 | .. | .. | 310 | 1766 |
| African oak .. | ·972 | .. | .. | 165 | 2589 |
| Dantzic oak .. | ·756 | .. | .. | 172 | 1470 |
| Ash .. .. .. | ·76 | 17,000 | 9,300 | 237 | 2026 |
| Beech .. .. | ·696 | 22,000 | 9,300 | 195 | 1556 |
| Elm .. .. .. | ·553 | 13,200 | 10,300 | 101 | 1013 |
| Pitch pine .. | ·66 | .. | .. | 177 | 1632 |
| New England fir | ·553 | .. | .. | 317 | 1102 |
| Dantzic pine .. | ·649 | 8,000 | 5,400 | .. | 1426 |
| Mar Forest fir .. | ·696 | .. | .. | 93 | 1144 |
| Larch .. .. | ·556 | 10,200 | 5,500 | 152 | 1127 |
| Norway spar .. | ·577 | .. | .. | 210 | 1474 |
| Spruce fir .. .. | ·512 | 10,100 | 6,500 | .. | 1490 |
| Memel deal .. | ·590 | .. | .. | 116 | 1731 |
| Christiana deal | ·689 | 12,000 | 5,850 | 115 | 1562 |

NOTE.—The reduced value of E in this Table is found by dividing the original value of E, as given by Professor Barlow in his work on the Strength of Materials, by 1728.

In the application of the foregoing Table the rules for finding the strength of a rectangular beam of timber fixed at one end and loaded at the other, are given by Professor Barlow as follows:—"Multiply the value of S in the Table of Data by the area, and the depth of the section in inches, and divide that product by the leverage in inches, and the quotient will be the weight required in lbs.;" or "to determine the strength of a rectangular beam of timber when it is supported at the ends, and is loaded in the middle of its length: *rule* multiply the value of S in the Table of Data by four times the depth in inches, and by the area of the section in inches, and divide the product by the distance

Professor Barlow's rules for calculating strength of timber beams.

between the supports in inches, and the quotient will be the greatest weight the beam will bear in lbs." If the beam is not placed horizontally, the distance between the supports must be measured horizontally, and will be the length of bearing. A fourth of the breaking weight, as given by the formulæ, will be the greatest load to which a beam ought to be subjected in practice. "When the load is applied at any other point than the middle, it will be as the rectangle of the segments, into which the point divides the distance between the supports, is to the square of half that distance; so is the weight found by the rule to the weight the beam will sustain at the given point." When a beam is uniformly loaded, its breaking weight is twice that of a beam whose load is applied at the centre. The following formulæ of Professor Barlow will give all the information required for calculating the strength and other particulars of beams, &c.

Mode of taking dimensions.

One-fourth the breaking weight the limit of safety.

Beams loaded at intermediate points.

Beams uniformly loaded.

Formulæ for strength of beams.

1. When the beam is fixed at one end and loaded at the other.

$$W = \frac{S a d^2}{l}.$$

$$l = \frac{S a d^2}{W}.$$

$$\left.\begin{aligned} a &= \frac{l W}{S d^2} \\ d &= \sqrt{\frac{l W}{a S}} \end{aligned}\right\} \text{ In square beams } a = d = \sqrt[3]{\frac{l W}{S}}.$$

2. When supported at one end and loaded in the middle.

In this case therefore

$$W = \frac{4 a d^2 S}{l}.$$

$$l = \frac{4 a d^2 S}{W}.$$

$$\left.\begin{aligned} a &= \frac{l W}{4 d^2 S} \\ d &= \sqrt{\frac{l W}{4 a S}} \end{aligned}\right\} \text{ In square beams } a = d = \sqrt[3]{\frac{l W}{4 S}}.$$

3. When the beam is fixed at both ends and loaded in the middle. Strength of beams.

$$W = \frac{6ad^2S}{l}.$$

$$l = \frac{6ad^2S}{W}.$$

$$\left.\begin{aligned} a &= \frac{lW}{6d^2S} \\ d &= \sqrt{\frac{lW}{6aS}} \end{aligned}\right\} \text{In square beams } a = d = \sqrt[3]{\frac{lW}{6S}}.$$

4. When the beam is supported at both ends, and loaded at an intermediate point.

$$W = \frac{lad^2S}{mn}.$$

$$l = \frac{mnW}{ad^2S}.$$

$$\left.\begin{aligned} a &= \frac{mnW}{ld^2S} \\ d &= \sqrt{\frac{mnW}{laS}} \end{aligned}\right\} \text{In square beams } a = d = \sqrt[3]{\frac{mnW}{lS}}.$$

5. When the beam is fixed at both ends, and loaded at an intermediate point.

$$W = \frac{3lad^2S}{2mn}.$$

$$l = \frac{2mnW}{3ad^2S}.$$

$$\left.\begin{aligned} a &= \frac{2mnW}{3ld^2S} \\ d &= \sqrt{\frac{2mnW}{3laS}} \end{aligned}\right\} \text{In square beams } a = d = \sqrt[3]{\frac{2mnW}{3lS}}.$$

In the above formulæ

W = breaking weight in lbs.
$l$ = length in inches.
$a$ = breadth in inches.
$d$ = depth in inches.
S = the tabular value given in Table No. 38.
$m$ and $n$ represent distance from the points of support when the load is applied at an intermediate point on the beam.

In order "to determine the dimensions of a beam capable of supporting a given weight with a given degree of deflection when fixed at one end: *rule*, divide Deflection of beams.

Prof. Barlow's rule for arriving at the amount of deflection.

the weight in lbs. by the reduced tabular value of E, multiplied by the breadth and deflection, both in inches; then the cube root of the quotient multiplied by the length in feet will be the depth required in inches." "When the weight is uniformly distributed over the length of the beam, the deflection will be only $\frac{5}{8}$ths of the deflection from the same weight applied at the extremity, and in the rule consider the weight reduced in this proportion." "If the beam be a cylinder, the deflection will be 1·7 times the deflection of a square beam, other circumstances being the same.'

Deflection in beams with uniformly distributed load.

Cylindrical beams or shafts.

"To find the dimensions of a beam capable of sustaining a given weight with a given degree of deflection when supported at both ends: *rule*, multiply the weight to be supported in lbs. by the cube of the length in feet. Divide this product by 16 times the reduced tabular value of E, multiplied into the given deflection in inches, and the quotient is the breadth multiplied by the cube of the depth in inches."

*Note* 1.—"If the beam be intended to be square, then the breadth is equal to the depth, and the fourth root of the quotient is the depth required."

*Note* 2.—"If the beam be a cylinder, multiply the quotient by 1·7, and then the fourth root will be the diamater of the cylinder."

Strength of columns of timber.

"To determine the dimensions of a pillar or column to bear a given stress in the direction of its axis without sensible curvature: *rule*, multiply the weight to be supported in lbs. by the square of the length of the pillar in feet, and divide the product by 40 times the reduced tabular value of E, the quotient will be equal to the breadth multiplied by the cube of the least thickness; therefore, either the breadth or thickness will require to be fixed upon before the other can be found."

*Note* 1.—"If the pillar be square, its side will be the fourth root of the quotient."

*Note* 2.—"If the column be a cylinder, multiply the

tabular value of E (Table 38) by 24 instead of 40. The fourth root of the quotient in the rule will be the diameter of the cylinder."

The following formulæ as to the strength of wooden columns, as given by Mr. Eaton Hodgkinson, will be found useful :— Formulæ for strength of columns.

LONG COLUMNS.

$W = 10{\cdot}95 \frac{D^4}{L^2}$, solid square Dantzic oak (dry).

$W = 7{\cdot}81 \frac{D^4}{L^2}$, solid square of Red-deal (dry).

SHORT COLUMNS.

$$w = \frac{W.C}{W + {\cdot}75\,C}.$$

W = breaking weight of long columns in tons.
$w$ = breaking weight of short columns, less than 30 diameters long in tons.
L = length of the column in feet.
C = crushing force of material as given in Table No. 38, multiplied by sectional area of column.

The relative strength of columns having the same sectional area, but differing in the form of section, will be for a circular column = 100, triangular ditto = 110, square ditto = 93. The safe load to be applied to columns should not exceed one-tenth of the breaking weight. Relative strength of columns in reference to form of section. Safe load for columns.

## IRON AND OTHER METALS.

Iron and some other metals are extensively used by the sanitary engineer in carrying out his varied works. Iron is more or less found in every country, and in every geological formation. It is employed in the construction of sanitary works in three forms: either as cast iron, which is a carburet of iron; as wrought iron, which is cast iron decarbonized, or freed from its combined carbon; and as steel, which is iron having a smaller amount of carbon in combination than is found in cast iron. Cast iron is largely used in works of Form in which iron is used. Use of cast iron.

sewerage and water-supply. It is a metal which is easily moulded to any shape, and is well adapted for the formation of pipes, cylinders, flushing-doors, penstocks, columns, gullies, and a variety of other details. Of the quality of cast iron, it is classed by the manufacturer as No. 1, 2, 3, or 4, according to the amount of carbon which is in combination with the iron. No. 1 is an iron which is most highly carbonized, the carbonization diminishing with the number of the iron. The amount of carbon in combination with the iron varies from 2 to 4 per cent. The proper admixture of the iron in the foundry is one of considerable importance in order to ensure a perfect casting; for as different varieties of iron have different points of fusion and varying rates of cooling, unless a proper admixture is ensured the casting will have within itself an element tending to produce its own destruction, for while some of the metal may be in perfect fusion, other parts may be imperfectly fused, while again others may be burnt; or in cooling, some of the metals may cool faster or slower than others, consequently the casting may be thus brought into a state of unequal tension, or, as it is technically termed, "hide-bound," when such slight influences as sudden change of temperature may lead to its instant destruction. Experiment has shown that castings which are made by remelting the iron in the air-furnace are capable of bearing a slightly greater tensile strain than those made direct from the blast-furnace; therefore it is the practice of some engineers to stipulate that the metal shall be remelted in the air-furnace. In the ordinary course of manufacture some of the largest and best makers of cast-iron pipes cast them direct from the blast-furnace, and if care is exercised no evils arise from this practice, as the men employed in the manufacture know from long experience, from the appearance of the flower on the molten metal, if it is or is not fit for pipe making, and if not suitable it is run into pigs, and afterwards remelted with an admixture of other iron in the air-furnace. In all castings the engineer should see that they are free

Classification of cast iron.

Admixture of iron.

Unequal tension in iron castings.

Air-furnace.

Blast-furnace.

from air-bubbles, scoria, cold-shot, and other imperfections of casting, and that they are allowed to cool slowly. There are, however, faults to which all articles made of cast iron are liable, and which may escape observation even after the most careful scrutiny, and in consequence there will ever remain a certain degree of uncertainty as to the strength of iron castings, for there are numerous circumstances which may, more or less, affect the quality of the manufactured article, such as unequal contraction in cooling, imperfections from latent flaws which may be concealed by a covering of sound metal, the brittle nature of the material, the presence of some deleterious agent in the metal itself, all tending to render cast iron more or less uncertain and liable to fail without warning. The presence of phosphorus in iron, which is more or less present in most of the ores of this country, greatly detracts from the quality of the material, and gives it a quality commonly known as "cold-short." The iron in this case appears to set in large crystals, and is brittle and very liable to fracture. The presence of sulphur in iron, on the other hand, gives it a quality known as "red-short," while the presence of arsenic is supposed to improve the quality of the material. The Lowmoor iron is supposed to derive its excellent quality from the presence of arsenic.

Faults of cast-iron work.

Fails without warning.

Phosphorus in iron.

Sulphur in iron.

Arsenic in iron.

Some other metallic bases when present have also a beneficial influence in purifying iron in the course of its manufacture, and are occasionally added by the manufacturer for this purpose, such, for example, as silica and manganese. Formerly iron was procured entirely by means of the cold blast, but the hot blast is now generally used, as a much larger yield of iron is produced at a less cost, and ores that could not be reduced with the cold blast are now successfully operated upon with the hot blast. It has been generally supposed that the hot-blast iron is inferior to cold blast, and practical tests applied to both irons appear to favour this view; yet the slight inferiority of the hot-blast iron

Purification of iron.

Comparison between cold and hot blast iron.

may not be due to the nature of the blast, but, as some persons of great experience in this branch of manufacture ascribe it, to the inferior ores which are now smelted as compared with those used when the cold-blast iron was more in vogue. As cast iron is more generally used in sanitary works in the form of cylinders or pipes, it is customary for small pipes with bands for drilling to be cast in the foundry on a bed laid nearly horizontal, or at an angle of 45°. Larger pipes of six inches and greater diameter are best cast vertically. In vertical castings the socket ends, if they are socket and spigot pipes, may be cast downwards, or upwards, as required. If large pipes are cast horizontally, the cores are apt to float, so that the pipe, when made, is liable to be thinner on one side than the other. Unequal thickness may occur in pipes vertically cast if the core is not placed truly concentric, or if it warps in the drying process. In horizontal-cast pipes core nails are required for fixing the core in position, and these are afterwards hammered up, so that it is easy to detect, by the presence or absence of these core nails, if the pipe has been horizontally or vertically cast. In all iron pipes the engineer should be careful to see that the castings are all truly cylindrical, and that the spigot of every socket pipe fits properly into the socket; that all special pipes, such as bends and junctions, are truly shaped and will join properly with the straight pipes; that the sectional area of every pipe be truly concentric, and any pipe which deviates more than one-fourth from the specified thickness at any point should be rejected. The elasticity of cast iron is such that an alternating load of one-sixth the breaking weight will injure it. The safe load for cast iron should not exceed one-tenth the breaking weight, and the average tensile strength may be taken at seven tons per square inch. When cast iron is used in the form of pipes, the mode adopted in practice, of arriving at the proper thickness of the pipe, is based equally on the experience of casting them as upon the calculated thickness that would result when

Cast-iron pipe manufacture.

Matters to be observed in pipe manufacture.

Effect of moving loads on cast iron.

Strength of cast-iron.

Strength and thickness of cast-iron pipes.

taking into account the pressure they would have to bear; and it will be found that any pipe which can be cast sound in the foundry will bear the ordinary pressure to which it may be subjected in practice. The reason for this is that cast iron is slightly porous, and is liable to considerable defects in casting, especially when the metal is thin; therefore all pipes are made of considerably greater thickness than that required to ensure their stability when subjected to a given bursting pressure. Some engineers make the thickness of a pipe equal one-fifth of the square root of its internal diameter in inches, which gives a thickness safe in practice for all ordinary pressures. The resistance which a pipe offers for every inch of its length to the internal pressure tending to burst it, equals that of the cohesive strength of the thickness of its two sides. The effective area of pressure upon the pipe tending to cause rupture equals its internal diameter. If the tensile strength of cast iron is taken at 15,000 lbs. to the square inch, the weight of a cubic foot of water being 62·449 lbs., then the thickness of a pipe to resist water pressure is

$$= \frac{62{\cdot}449 \text{ H D}}{2 \times 144 \times 15000} = {\cdot}0000144 \text{ H D}.$$

Formula for strength of cast-iron pipes.

H = head of water in feet.
D = diameter of pipe in inches.

With this thickness the pipe would be at the point of bursting. All pipes should be made of sufficient thickness not only to bear the steady working pressure, but the shocks to which they are subjected when water is put in motion through them or the current is suddenly stopped. In practice it may be taken that pipes should be capable of sustaining ten times the greatest pressure, or the strain to which at any time they may be subjected, which is the pressure used in testing them; therefore if pipes are so made, the following formula will give their thickness ·000144 H D.

Pipes should be made to resist ten times the bursting pressure.

H = head of water in feet.
D = internal diameter of pipe in inches.

Formula for thickness of pipes.

Pipes are usually tested in a hydraulic machine to a test of three or four times the greatest working pressure to which they will be subjected in practice. When pipes are made according to the formula ·000144 H D, the safe head of water to which they should be tested equals one-tenth the bursting pressure. Example, a 12-inch pipe is required to be made to work under a constant pressure of 125 feet head of water. This pipe would be tested say to $125 \times 3 = 375$ feet, and its thickness should equal $\cdot 000144 \times 375 \times 12 = \cdot 648$ inches, while its bursting pressure $= \frac{648 \times 2 \times 15000}{12} =$ 1620 lbs. per square inch. A machine for pipe testing is illustrated in Fig. 42. It consists of a frame carrying a movable head A. The apparatus is capable of being lengthened at pleasure by means of the nuts B, B, so as to take in pipes of varying length. The pipe C to be tested is rolled up an inclined plane, usually of timber, into its position; the movable head is then screwed up, the pipe being kept water-tight at the ends by means of packing, composed of either platted

Example.

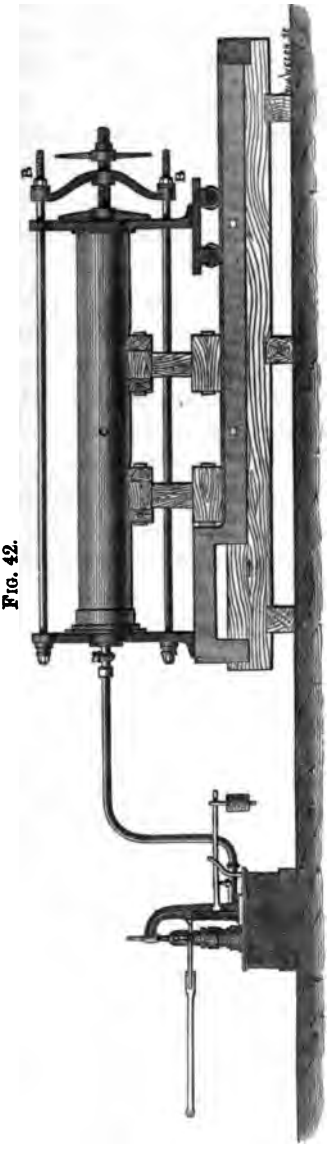


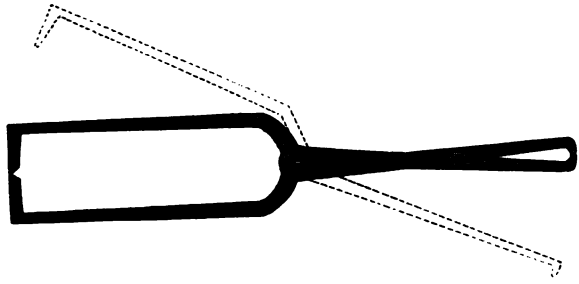

FIG. 42.

Pipe testing by pressure.

hemp or a disk of india-rubber or leather. The pressure is applied by means of a force pump; a gauge is fixed upon the apparatus in order to record the pressure, and as the pipe fills with water provision is made for the escape of the air, this precaution being absolutely necessary, or otherwise a pipe bursting would explode with considerable violence. The thickness of the pipes is usually tested by means of a pair of callipers, as shown in Fig. 43.

Pipe testing for thickness.

FIG. 43.



In Table No. 38, the diameter, thickness, length, weight, safe head of water, and the bursting pressure is given for pipes of from 1½ inch to 48 inches diameter. In cases in which the thickness for pipes required does not correspond with the thickness given in the Table, the weight of the pipe may be arrived at by taking its cubical contents in inches and multiplying it by ·27 lb., the weight of one cubic inch of cast iron.

Table No. 38.

How weight of pipes ascertained.

TABLE No. 38.—Showing the SIZE, WEIGHT, SAFE HEAD, and STRENGTH of CAST-IRON WATER-PIPES.

| Internal diameter of Pipe in inches. | Thickness of Metal in inches. | Length of Pipe in work in feet. | Depth of Socket in inches. | Thickness of Joint in inches. | Weight of Pipe in lbs. | Deviation which may be allowed in Weight in lbs. | Safe Head of Water in feet. | Bursting Pressure in lbs. per sq. in. tensile strength taken at 15,000 lbs. per sq. in. |
|---|---|---|---|---|---|---|---|---|
| 1½ | ·250 | 6 | 2·75 | ·20 | 42 | 2 | 1150 | 5000 |
| 2 | ·250 | 6 | 2·75 | ·20 | 56 | 2 | 863 | 3750 |
| 3 | ·250 | 9 | 2·75 | ·20 | 80 | 3 | 575 | 2500 |
| 3 | ·375 | 9 | 2·75 | ·20 | 120 | 4 | 863 | 3750 |
| 3 | ·500 | 9 | 2·75 | ·20 | 165 | 6 | 1150 | 5000 |
| 3 | ·625 | 9 | 2·75 | ·20 | 210 | 7 | 1438 | 6250 |
| 4 | ·250 | 9 | 2·75 | ·26 | 110 | 4 | 431 | 1875 |
| 4 | ·375 | 9 | 2·75 | ·26 | 160 | 6 | 647 | 2812 |
| 4 | ·500 | 9 | 2·75 | ·26 | 210 | 7 | 863 | 3750 |
| 4 | ·625 | 9 | 2·75 | ·26 | 260 | 8 | 1078 | 4687 |
| 5 | ·250 | 9 | 2·75 | ·26 | 135 | 5 | 345 | 1500 |
| 5 | ·375 | 9 | 2·75 | ·26 | 195 | 7 | 518 | 2250 |
| 5 | ·500 | 9 | 2·75 | ·26 | 270 | 8 | 690 | 3000 |
| 5 | ·625 | 9 | 2·75 | ·26 | 330 | 10 | 863 | 3750 |
| 6 | ·375 | 9 | 2·75 | ·26 | 230 | 7 | 431 | 1875 |
| 6 | ·500 | 9 | 2·75 | ·26 | 255 | 8 | 575 | 2500 |
| 6 | ·625 | 9 | 2·75 | ·26 | 385 | 11 | 719 | 3125 |
| 6 | ·750 | 9 | 2·75 | ·26 | 470 | 14 | 863 | 3750 |
| 7 | ·375 | 9 | 2·75 | ·26 | 275 | 8 | 370 | 1607 |
| 7 | ·500 | 9 | 2·75 | ·26 | 360 | 10 | 493 | 2142 |
| 7 | ·625 | 9 | 2·75 | ·26 | 450 | 13 | 616 | 2678 |
| 7 | ·750 | 9 | 2·75 | ·26 | 540 | 15 | 739 | 3214 |
| 8 | ·375 | 9 | 2·75 | ·26 | 310 | 9 | 323 | 1406 |
| 8 | ·500 | 9 | 2·75 | ·26 | 410 | 12 | 431 | 1875 |
| 8 | ·625 | 9 | 2·75 | ·26 | 510 | 15 | 539 | 2343 |
| 8 | ·750 | 9 | 2·75 | ·26 | 610 | 18 | 647 | 2812 |
| 9 | ·375 | 9 | 2·75 | ·26 | 345 | 10 | 288 | 1250 |
| 9 | ·500 | 9 | 2·75 | ·26 | 450 | 13 | 383 | 1666 |
| 9 | ·625 | 9 | 2·75 | ·26 | 560 | 16 | 479 | 2083 |
| 9 | ·750 | 9 | 2·75 | ·26 | 680 | 18 | 575 | 2500 |
| 10 | ·375 | 9 | 2·75 | ·26 | 380 | 10 | 259 | 1125 |
| 10 | ·500 | 9 | 2·75 | ·26 | 500 | 15 | 345 | 1500 |
| 10 | ·625 | 9 | 2·75 | ·26 | 620 | 18 | 432 | 1878 |
| 10 | ·750 | 9 | 2·75 | ·26 | 775 | 20 | 518 | 2250 |
| 11 | ·500 | 9 | 2·75 | ·26 | 545 | 15 | 313 | 1363 |
| 11 | ·625 | 9 | 2·75 | ·26 | 680 | 18 | 392 | 1704 |
| 11 | ·750 | 9 | 2 75 | ·26 | 815 | 24 | 470 | 2045 |
| 11 | ·875 | 9 | 2·75 | ·26 | 960 | 27 | 549 | 2386 |
| 12 | ·500 | 9 | 3·00 | ·33 | 595 | 17 | 288 | 1250 |
| 12 | ·625 | 9 | 3·00 | ·33 | 740 | 20 | 359 | 1562 |
| 12 | ·750 | 9 | 3·00 | ·33 | 890 | 22 | 431 | 1875 |
| 12 | ·875 | 9 | 3·00 | ·33 | 1040 | 30 | 503 | 2187 |
| 14 | ·625 | 9 | 3·00 | ·33 | 890 | 24 | 308 | 1339 |
| 14 | ·750 | 9 | 3·00 | ·33 | 1060 | 30 | 370 | 1607 |
| 14 | ·875 | 9 | 3·00 | ·33 | 1230 | 35 | 431 | 1875 |
| 14 | 1·00 | 9 | 3·00 | ·33 | 1400 | 40 | 493 | 2142 |

TABLE No. 38.—Showing the SIZE, WEIGHT, SAFE HEAD, and STRENGTH of CAST-IRON WATER-PIPES—(*continued*).

| Internal diameter of Pipe in inches. | Thickness of Metal in inches. | Length of Pipe in work in feet. | Depth of Socket in inches. | Thickness of Joint in inches. | Weight of Pipe in lbs. | Deviation which may be allowed in Weight in lbs. | Safe Head of Water in feet. | Bursting Pressure in lbs. per sq. in. tensile strength taken at 15,000 lbs. per sq. in. |
|---|---|---|---|---|---|---|---|---|
| 15 | ·625 | 9 | 3·00 | ·33 | 945 | 27 | 288 | 1250 |
| 15 | ·750 | 9 | 3·00 | ·33 | 1125 | 32 | 345 | 1500 |
| 15 | ·875 | 9 | 3·00 | ·33 | 1315 | 35 | 403 | 1750 |
| 15 | 1·00 | 9 | 3·00 | ·33 | 1495 | 40 | 460 | 2000 |
| 16 | ·625 | 9 | 3·50 | ·33 | 1005 | 28 | 269 | 1171 |
| 16 | ·750 | 9 | 3·50 | ·33 | 1200 | 35 | 323 | 1406 |
| 16 | ·875 | 9 | 3·50 | ·33 | 1395 | 39 | 377 | 1640 |
| 16 | 1·00 | 9 | 3·50 | ·33 | 1595 | 45 | 431 | 1875 |
| 18 | ·625 | 9 | 3·50 | ·33 | 1125 | 32 | 239 | 1041 |
| 18 | ·750 | 9 | 3·50 | ·33 | 1340 | 36 | 288 | 1250 |
| 18 | ·875 | 9 | 3·50 | ·33 | 1530 | 42 | 335 | 1458 |
| 18 | 1·00 | 9 | 3·50 | ·33 | 1745 | 50 | 383 | 1666 |
| 21 | ·625 | 12 | 3·50 | ·33 | 1750 | 50 | 205 | 892 |
| 21 | ·750 | 12 | 3·50 | ·33 | 2075 | 56 | 246 | 1071 |
| 21 | ·875 | 12 | 3·50 | ·33 | 2410 | 68 | 288 | 1250 |
| 21 | 1·00 | 12 | 3·50 | ·33 | 2855 | 70 | 328 | 1428 |
| 24 | ·625 | 12 | 3·50 | ·33 | 1980 | 54 | 180 | 781 |
| 24 | ·750 | 12 | 3·50 | ·33 | 2350 | 65 | 216 | 937 |
| 24 | ·875 | 12 | 3·50 | ·33 | 2800 | 70 | 251 | 1093 |
| 24 | 1·00 | 12 | 3·50 | ·33 | 3185 | 80 | 288 | 1250 |
| 30 | ·75 | 12 | 4·00 | ·33 | 3080 | 78 | 173 | 750 |
| 30 | 1·00 | 12 | 4·00 | ·33 | 3940 | 105 | 230 | 1000 |
| 30 | 1·125 | 12 | 4·00 | ·33 | 4205 | 110 | 259 | 1125 |
| 30 | 1·25 | 12 | 4·00 | ·33 | 4955 | 112 | 288 | 1250 |
| 36 | ·75 | 12 | 4·00 | ·33 | 3675 | 100 | 144 | 625 |
| 36 | 1·0 | 12 | 4·00 | ·33 | 4785 | 111 | 192 | 833 |
| 36 | 1·125 | 12 | 4·00 | ·33 | 5195 | 113 | 216 | 937 |
| 36 | 1·25 | 12 | 4·00 | ·33 | 5900 | 125 | 239 | 1041 |
| 42 | ·75 | 12 | 4·50 | ·33 | 4365 | 110 | 123 | 535 |
| 42 | 1·0 | 12 | 4·50 | ·33 | 5645 | 120 | 164 | 714 |
| 42 | 1·125 | 12 | 4·50 | ·33 | 6300 | 130 | 185 | 803 |
| 42 | 1·25 | 12 | 4·50 | ·33 | 6940 | 140 | 205 | 892 |
| 48 | ·75 | 12 | 4·50 | ·33 | 4980 | 112 | 108 | 468 |
| 48 | 1·0 | 12 | 4·50 | ·33 | 6450 | 132 | 144 | 625 |
| 48 | 1·125 | 12 | 4·50 | ·33 | 7180 | 142 | 162 | 703 |
| 48 | 1·25 | 12 | 4·50 | ·33 | 7615 | 150 | 180 | 781 |

Example of uncertainty of cast iron.

As a practical example of the uncertainty of cast iron and the difficulty of ascertaining the soundness of iron castings, a circumstance came under the author's attention, when carrying out a portion of the water-works of Croydon, which is worthy of being recorded. A 12-inch water-main five-eighths of an inch in thick-

ness was laid through the district, and the pipes were tested, previous to being laid, at the manufacturer's works, to a pressure of 500 head of water. The greatest working pressure on the main did not exceed 120 feet head of water. When this main was first put in operation several pipes burst, and on this account it was thought expedient to test the main again, which was accordingly done, to a pressure equal to 400 feet head of water; in spite of this second test, after some few months had elapsed, three pipes, each at some considerable distance apart, burst simultaneously, causing considerable damage to property. It should be observed that this main was laid in a porous gravel soil in a trench 4 feet deep, and that for some weeks previous to the bursting there had been almost uninterrupted rainfall, consequently the ground was thoroughly saturated with moisture, and a few hours previous to the bursting of the main there was a fall of several inches of snow followed immediately by rain. Inquiries made as to the mode of the manufacture of these pipes showed that they had been hastily made, and probably too rapidly cooled; impurities may also have been present in the metal which had deranged the crystalline process, and these circumstances combined to render them "cold-short," and probably "hide-bound," and the sudden change of temperature caused them to fly to pieces in a manner analogous to the breaking of an unannealed glass by the pouring in of hot water. In support of the foregoing view, as to the cause of the failure of these pipes, it may be said that they could not have failed from pressure, as the main in question drew its supply from a larger main, which was relatively not so strong, and, moreover, samples of the burst pipes when tested were found capable of sustaining a pressure exceeding eight tons to the square inch of section. It is, moreover, well known from experience, that cylinders of cast iron have flown to pieces when subjected to any sudden change of temperature, especially such as cold rain or severe frost, and that the majority of breakages

Description of pipes used.

Cause of failure.

Effects of sudden changes of temperature.

in cast-iron water-pipes usually occurs in time of frost, a sudden, severe frost being almost sure to cause considerable breakage of pipes.

Use of wrought iron.

*Wrought Iron* forms more or less an essential feature in constructions for sanitary purposes. Its use for tubes for gas and water, girders, valve gear, tide valves, steam-boilers, machinery, and a variety of other purposes, is well known, and its value consists in its great strength and capability of being easily worked into various forms. Like cast iron, it is subject to differences in quality; it is as a rule divided into two kinds, according to the nature of the fracture, one of which is said to be fibrous, tough, or "red-short," and the other granular or "cold-short." The presence of foreign substances in wrought iron has an analogous effect upon it to that which they have upon cast iron; for example, phosphorus is said to render wrought-iron bars "cold-short," while sulphur renders them "red-short." Dr. Fairbairn, in his work on Iron Manufacture, says, "The former is the most ductile, and is a tough fibrous material, which exhibits considerable strength when cold; the latter is more brittle, and has a highly crystalline fracture, almost like cast iron, but the fact is probably not generally known that the brittle works as well and is as ductile under the hammer as the other when at a high temperature." Of all the qualities of iron preference should be given, as Mr. Kirkaldy states, to puddled iron, instead of scrap iron, which latter may be composed of a variety of qualities of iron, all of which may differ as to their welding points; when therefore they are worked together one portion may be too much heated, and so destroy the value of that particular iron, while other portions may not be sufficiently heated, and an imperfect quality of iron is the result of such amalgamations. All plates and bars, especially when rolled, are much stronger in the direction of the fibre than in the contrary way. The long-continued heating of wrought iron has a tendency to render it crystalline in character, and to injure

Variations in quality of wrought iron.

Dr. Fairbairn.

Mr. D. Kirkaldy gives preference to puddled iron.

Influence of fibre on strength.

Assortment of wrought iron.

its quality. In the manufacture of wrought iron its quality is designated by the number of times the iron undergoes working in the course of manufacture; for instance, it is called best, best best, treble best, &c., according to the number of times it has been worked; but there is a limit to the value of iron so reworked, as Mr. Kirkaldy has found that after five or six workings the tensile strength of the iron is deteriorated, so no advantage results from incurring the greater cost of re-working an unlimited number of times. In ordering wrought-iron work it will be well for the engineer to stipulate the breaking weight he expects the iron to bear. Many engineers also take into consideration the amount of elongation taking place in the specimen before fracture. Mr. Kirkaldy, who has given a considerable amount of attention to the quality of iron, considers that it is better to take into consideration the contraction of the area in breaking, because then you will get to know the quality of the iron you have to deal with, and he says, "It seems most remarkable that an element of the highest importance should have been so long overlooked, namely, the contraction of the specimen's area when subjected to considerable strain, and the still greater contraction at the point of rupture which takes place in a greater or less degree as the material is soft or hard, and the consequent influence this reduction must have on the amount of weight sustained by the specimen before breaking. The apparent mystery of a very inferior description of iron suspending, under a steady load, fully a third more than a very superior kind, vanishes at once when we find that the former had the benefit of retaining to the last its original area only slightly decreased, whilst the latter on breaking was reduced to very nearly a fourth of its original area—the one a hard and brittle iron, liable to snap suddenly under a jerk or blow, the other very soft and tough, impossible to break otherwise than by tearing slowly asunder." Therefore, in selecting wrought iron for any particular purpose

Breaking weight should be stated.

Contraction of area in breaking should be noted.

Quotation from Mr. Kirkaldy.

it will be well for the engineer to state the degree of contraction he will expect when it is tested in the breaking apparatus. Degree of contraction should be stated.

In Table No. 39 some experiments on the strength and contraction of metals are given which will aid the engineer in the prosecution of his works. It is

TABLE No. 39.—Showing the SPECIFIC GRAVITY, TENSILE and COMPRESSIVE STRENGTH of various metals. From experiments by Mr. D. KIRKALDY and others.

| Description of Metal. | Specific Gravity, Water = 1·000. | Reduction of Fractured Area per cent. | Tensile Strength in lbs. per sq. in. | Compressive Strength in lbs. per sq. in. |
|---|---|---|---|---|
| **Cast steel for tools from Acadian iron** | 7·823 | 4·7 | 132,900 | |
| **Bessemer steel for tools, in bar** | 7·820 | 22·3 | 111,460 | |
| **Ditto cooled in oil** | .. | .. | 211,072 | |
| **Blister steel bars** | 7·720 | 21·4 | 104,290 | |
| **Krupp's steel bars** | .. | 34·0 | 92,000 | |
| **Mersey puddled steel bars** | .. | 35·3 | 71,480 | |
| Ditto steel plates for ships | .. | 5·4 | 93,200 | |
| Ditto mild steel plates | .. | 10·5 | 72,360 | |
| Blochairn steel boiler-plates | 7·64 | 7·1 | 85,000 | |
| Homogeneous metal rolled bars | .. | 36·6 | 90,600 | |
| Ditto forged bars | .. | 26·0 | 89,700 | |
| Ditto plates | 7·802 | 15·2 | 96,700 | |
| Lowmoor iron bars | .. | 48·5 | 60,360 | |
| Ditto plates | 7·699 | 15·9 | 51,250 | |
| Bowling iron bars | .. | 45·3 | 62,400 | |
| Ditto plates | .. | 11·1 | 49,380 | |
| Glasgow B best bars | 7·650 | 39·6 | 58,880 | |
| Ditto best boiler-plates | .. | 8·8 | 51,340 | |
| Cast iron | 7·000 | .. | 13,440 | 80,600 |
| Ditto | 7·600 | .. | 29,120 | 143,360 |
| Wrought iron | .. | .. | .. | 35,000 to 40,000 |
| Steel | .. | .. | .. | 200,000 to 336,000 |
| Cast brass | 8·400 | .. | 18,000 | |
| Gun metal | 8·462 | .. | 34,000 | |
| Copper, cast | 8·607 | .. | 18,800 | |
| Ditto, sheet | 8·780 | .. | 30,000 | |
| Tin, cast | 7·290 | .. | 4,500 | 15,000 |
| Zinc, cast | 7·000 | .. | 7,400 | |
| Silver | 10·474 | .. | 40,760 | |
| Gold | 19·361 | .. | 20,400 | |
| Lead, cast | 11·360 | .. | 1,800 | 7,000 |
| Ditto, sheet | 11·400 | .. | 3,360 | |
| Aluminium, bronze | 7·68 | .. | 71,650 | 130,120 |
| Platinum, sheet | 23·000 | .. | .. | |
| Bismuth, cast | 9·822 | .. | 3,200 | |

Tests for ascertaining the fibre of the iron.

also advisable to ascertain the nature and texture of the iron, whether it is coarse or fine, or whether the fibres lie in the direction in which the strain is likely to be brought upon the material. For this purpose Mr. Kirkaldy introduced a very simple method of examining the fibre of the iron. He immersed pieces of the metal in dilute hydrochloric acid, which acting on the surrounding impurities has the effect of removing them, leaving to view only the metallic portion of the iron. By a simple test of this kind it is easy to ascertain whether the iron is fibrous or crystalline. In this country the regulations of the Board of Trade with regard to structures limit the stress that any particular bridge or work should bear to five tons per square inch. This seems about the right limit for safety, for Dr. Fairbairn has shown that structures liable to changes of load are not safe when subject to a strain of seven tons per square inch of section. In all works of engineering, except in cases in which the materials are welded together, it is more or less necessary to secure the work by means of riveted joints. Rankine has calculated that with rivets and bolts which fit accurately the holes in which they are placed the resistance to shearing varies exactly as the sectional area of the material in the place of rupture, and may be taken as 32,500 lbs. per square inch for cast iron, and 50,000 lbs. per square inch wrought iron. Dr. Fairbairn calculates that in consequence of the punching of a plate the strength is reduced as follows:—

Board of Trade Regulations as to strains on structures.

Dr. Fairbairn's experiments.

Riveted joints.

Shearing strength of iron.

| | |
|---|---|
| Assuming for the strength of the plate .. .. .. | 100 |
| The strength of the double riveted joint will be .. | 68 |
| And that of the single riveted joint .. .. .. | 46 |

Relative strength of riveted joints.

Rule for riveted joints.

For riveted joints some engineers advise that the diameter of the rivet used should be twice the thickness of the plate, and the pitch or the distance from centre to centre of rivet should be two-and-a-half times the diameter of the rivet. This rule makes the rivets

rather stronger than the plates. To arrive at perfectly correct results the tensile strength of the plate between the rivet holes and the shearing strength of the rivets should be equal. The tensile strength of good Staffordshire or Yorkshire plates, after allowing for the weakening of the plate by punching, may in practice be taken at 18 tons per square inch, and the shearing of the rivet at 25 tons per square inch. Wherever great strength of joint is required double riveting should be resorted to, and in bridge work chain riveting is used. Both cast and wrought iron are affected by the influence of frost, being much more brittle in time of frost than at higher temperatures. The practice of galvanizing wrought and cast iron, which is common in sanitary works, somewhat impairs the strength of the iron, but as the oxidation of all ironwork should be particularly guarded against, or otherwise rapid destruction will follow, galvanizing forms one of the best protections when iron is brought into contact with sewage or the moist air of sewers.

Strength of plates and rivets.

Double riveting.

Influence of frost on strength of iron.

Oxidation to be prevented.

*Steel* is another form of iron. In its chemical composition it stands midway between that of cast and wrought iron. Steel is largely used for the bearings of machinery and in cases where great strength and lightness of structure are required. In the manufacture of steel the object to be gained is either to carbonize wrought iron, or to decarbonize cast iron. The process now generally adopted, known as Bessemer's process, is one that has caused a complete revolution in the manufacture of steel. It has already been shown that cast iron contains from 2 to 4 per cent. of carbon. If this carbon be reduced to 1 per cent. and the metal freed from other impurities, we have steel. The Bessemer process consists in decarbonizing cast iron as distinguished from the older process of carbonizing wrought iron. The mode of operation consists in forcing air and steam through the molten cast iron in a suitable vessel, when the heat generated by the combustion of the carbon in combination with the cast iron is so intense

Use of steel, and its manufacture.

Bessemer's process.

as to keep up the operation without the aid of any further fuel. Owing to the impurities in the iron and the difficulty of arriving at a proper amount of decarbonization, it is found desirable in practice to make a selection of pure irons for the manufacture of steel by this process, and to completely decarbonize them, and then to add a quantity of iron containing a known amount of carbon. This process is now so satisfactorily performed, that metals of uniform quality and strength can be produced with the greatest certainty, and the cost of production is even less than that of wrought iron when manufactured by the old plan. Steel and wrought iron are also made by Mr. Heaton's process, which consists in at once converting cast iron by the use of nitrate of soda into iron or steel. The salts of iron have been largely used for the deodorization and precipitation of sewage matter, and also as a disinfectant.

Heaton's process.

Salts of iron.

Use of copper.

*Copper* is a metal that is used in sanitary works, more especially in connection with waterworks and the interior fittings of houses, as for the construction of baths, hot-water apparatus, floating balls for cistern valves, &c. It is also extensively used alloyed with other metals, as with tin, zinc, and lead. When mixed in the proportion of one of tin to nine of copper the alloy is termed gun-metal. This metal is extensively used in the bearings of machinery, the spindles, nuts of sluices, and other valves. Gun-metal is also made by mixing tin and copper in other proportions, varying from 1 to 2½ oz. of tin to 16 oz. of copper, the former making a soft material, and the latter a material of considerable hardness. When mixed with zinc it forms brass, which is used for many purposes in connection with sanitary works, more especially for the details of house fittings, and for the construction of stop and bib-cocks in connection with waterworks. A very good alloy for the construction of water-fittings consists of 14 lbs. of copper, 1½ lb. lead, and 1 lb. block tin. Muntz's metal, another form of brass, is now extensively used,

Gun-metal.

Brass.

Alloy for water-fittings.

Muntz's metal.

especially for the protection of ships' bottoms. It consists of various preparations of zinc and copper, varying from 37 of zinc to 63 of copper, to 50 of zinc and 50 of copper. The alloys of copper are very much stronger than the original metals when subject to either compressive or tensile strains, as will be seen on examination of Table No. 39. The salts of copper are largely used for disinfecting purposes.

Strength of the alloys of copper.

Salts of copper.

*Tin* is a metal that is extremely valuable for sanitary works, especially for the conveyance of water in its pristine purity. It offers great resistance to the action of certain ingredients in water which rapidly act upon other metals, and lead to serious inconvenience by rendering the water unwholesome. It is used as a wash and lining for pipes of other metals, such as iron, lead, &c. The great expense of tin precludes its entire use in water-fittings, except to the wealthy; but it is used as a lining for lead pipes, and owing to its having a greater tensile strength than lead, it can be used in combination with this latter metal; thus a lead pipe with a tin lining may be made equally strong as an ordinary lead pipe, and at about the same cost.

Use of tin.

Tin-lined pipes.

*Lead* is largely used in sanitary works, especially for the formation of small service pipes in waterworks. It is made of various sizes and thicknesses, in accordance with the circumstances and pressures of water it is to withstand, and it is extremely convenient for use in practice on account of its ductility. It is also used for the lining of cisterns, and the construction of ordinary household pumps, but care in its use needs to be exercised on account of the action of some waters upon it, whereby soluble salts of lead are formed, which if taken up into the system of the water-drinker lead to serious internal disorders. The oxides of lead are largely employed as the base in most pigments used in protecting iron and wood work.

Use of lead.

Value on account of ductility.

Danger of lead pipes.

Lead used as a pigment.

*Zinc* is also a material very extensively used in sanitary works. On account of its cheapness it is ordinarily

Use of zinc.

employed in the construction of ventilating pipes, cisterns, baths, rain-water pipes, and a variety of ornamental purposes in connection with sanitary works. It has also been adopted as a coating for the protection of other metals as in galvanizing. The objections to the use of zinc in connection with waterworks are as great as those against lead, as waters which will affect lead will equally attack zinc, forming poisonous salts. The salts of zinc are largely used for disinfecting purposes, and for the preservation of timber, and its oxide is employed as a pigment.

Objections to use of zinc.

Salts of zinc.

Use of silver.

*Silver* is used in sanitary works to some extent, many articles being plated with it. It has also been employed as a lining for lead water-pipes.

## FOUNDATIONS FOR SEWERS.

In some districts, owing to the treacherous or unstable character of the subsoil, it is necessary to make provision for securing a good foundation for sewers, as they must always be constructed at a certain definite level in order to effect their object, and they cannot be carried below that level to obtain, at a greater depth, a more stable foundation. Therefore, the best mode of providing artificial foundations when sewers have to be constructed in unfavourable situations, is a question for the engineer to consider. In some cases a good foundation may be secured by excavating the sewer trench to an additional depth, and afterwards filling it up to the level of the sewer with suitable materials. For example, in districts in which rubble-stone or boulders are plentiful, rough rubble walling may be resorted to; under other circumstances a continuous wall of concrete may be constructed under the sewer; or, as has been done in the

Necessity of constructing sewers at fixed levels.

Excavation of trench to greater depth.

Rubble wall foundation.

Concrete wall foundation.

# ARTIFICIAL FOUNDATIONS FOR SEWERS.

*Fig: 1.*

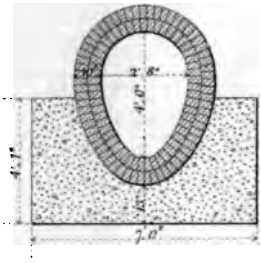


*Fig: 2.*

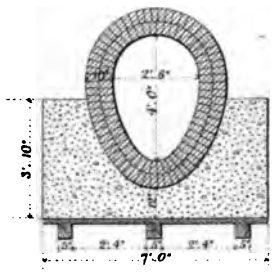


*Fig: 3.*

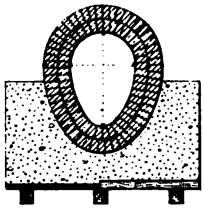


*Fig: 4.*

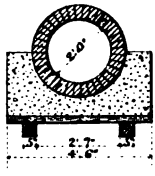


*Fig: 5.*

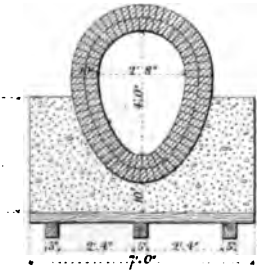


*Fig: 6.*

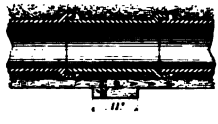


*Fig: 7.*

*Fig: 8.*

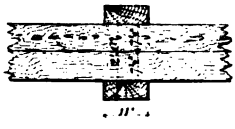


*Fig: 9.*

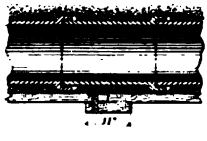


*Fig: 10.*

case of the northern outfall sewer of the Metropolis, when passing through the marshes below Barking, where in order to save the great cost of excavating the ground down to a firm formation, piers of concrete were constructed at intervals along the course of the sewer, which were afterwards connected by brick arches, so as to form, as it were, a kind of subterranean aqueduct. This kind of foundation will be found in some cases extremely serviceable. The arches, as well as the piers, may be constructed of concrete, the earth being excavated so as to form the natural centre for the concrete arch. In carrying out the sewerage works of Redhill in 1867, the author had to contend with very unstable soil in which to construct the sewers, the ground through which the sewers were carried in many cases being so extremely soft and boggy as to be dangerous to walk on; yet the sewers have been executed in the rotten bog and quicksand of this district in a perfectly satisfactory manner. The mode adopted was similar to the designs for the foundation of sewers, illustrated in Plate No. IV. When the ground was moderately solid, an entirely concrete foundation was used, as shown in Plate No. IV., Fig. 1. Where the ground was more treacherous, three lines of die square timber, 5½ inches square, were laid in the trench, which was excavated to a width of 6 feet in the clear. These poles were laid so as to break joint; on the top of these poles, or sleepers, closely-wattled hurdles were placed, and on these the concrete was placed, as shown in Fig. 2, Plate IV. In other cases, when the foundation was found extremely treacherous, a similar arrangement of fir-poles or sleepers as before was used, but they were closely covered with 3-inch planking, which was securely spiked down to the longitudinal sleepers, as shown in Fig. 5, Plate IV. Owing to the large amount of water present when excavating these works, it was found that if for only a short time the operation of pumping was discontinued, the subsoil water would rise and force itself through the newly-laid concrete or brickwork of the

Pier foundations.

Concrete arches for foundations.

Example: sewers at Redhill.

Description of Plate No. IV. Concrete foundation.

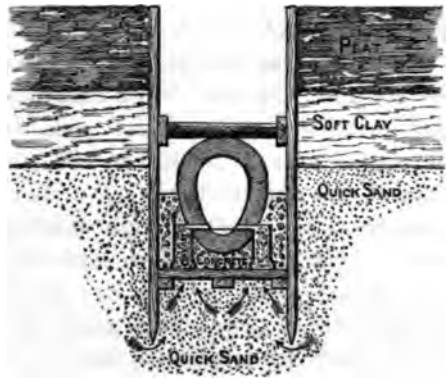
Timber, hurdles, and concrete foundation.

Plank foundation.

Admittance of subsoil water into sewer.

sewer; consequently it became necessary to make provision for admitting this water into the sewers during the progress of the works, in such a way as to allow the materials a fair chance of consolidation before finally excluding the water. This was done as shown in Fig. 44,

FIG. 44.




Description of Fig. 44.

which represents a sewer constructed upon an artificial plank and concrete foundation. At suitable intervals along the line of sewer ordinary sewer pipes were placed upon the planks socket downwards, and afterwards filled with clean gravel, a communication being made by means of a land drain communicating with the bottom of the sewer. The water passed up through the planked floor and gravel, discharging itself, free of sand, into the sewer; so that the water, having a free escape, did not injuriously affect the work, and pumping could therefore be dispensed with after the completion of the lower portion of the sewer; and owing to the small apertures left for the purpose of receiving the spring water, at any time that may be thought desirable after the consolidation of the work, the spring water could be effectually shut out. In Plate No. IV., Fig. 3, is shown the design for the artificial foundations of one of the sewers of Dantzic, which in some portions was intended to be constructed on wattled hurdles, and the other portions

Separation of sand from water.

Foundations of Dantzic sewers.

on closely-planked foundations. Fig. 4 also represents a 2-feet sewer upon a plank and concrete foundation. Fig. 5 represents an oval sewer upon a plank and concrete foundation. Fig. 6 shows a longitudinal section of a plank foundation for earthenware pipes of 12 inches and smaller diameter. Fig. 7 shows a transverse section of the same. Fig. 8 shows a plan of a plank foundation for sewer pipes of 15 inches and larger diameter. Fig. 9 represents a longitudinal section of the same, and Fig. 10 a transverse section. It is only necessary to add, with regard to these planked foundations, that in cases where single planks are used for the foundation of a sewer, as shown in Figs. 6 and 7, a cross-sleeper should be laid under the ends of the planks; or, in cases where two planks laid side by side to form a foundation, as shown in Fig. 8, the plank should be laid to break-joint and at the point at which the joints are broken a transverse sleeper should be laid under the planking. It is also necessary, in order to ensure the safety of the sewer, that a sufficient amount of material, such as good earth, should be laid over the plank foundation, so as to prevent the pipes taking a bearing from socket to socket, and so act as girders with the weight of the superincumbent earth upon them. The pipes should bear uniformly on the plank, and to secure this a sufficient depth of good material must be laid upon the planks to prevent the sockets touching them. Artificial foundations may be carried out on the foregoing principles for carrying sewers of any size, as it is quite possible to construct a raft foundation of sufficient area to carry the heaviest sewer over the most unstable ground. It would, however, be well in carrying out such artificial foundations that experiments should be made before the work is fully carried out, by first constructing a length of the work and testing its capability of carrying its intended load, by weighting it to an amount equal to the weight of the sewer with its charge of sewage and the superincumbent earth which

Description of Plate IV.

Precautions to be taken with plank foundations.

Pipes must not rest on sockets.

Artificial foundations constructed for sewers of any size.

Experiments should be made to test new foundations.

Test at Redhill.

may rest upon it. This test was applied in the case of Redhill, and it was found that for a sewer 3 feet by 2 feet 6 inches internal diameter, constructed in ground which would not bear men to walk upon without sinking, that with an artificial foundation 6 feet wide, when weighted, after fourteen days showed no perceptible subsidence, and the work was prosecuted to completion, and has not since shown the slightest sign of settlement or failure.

Pile foundations.

In some cases, in constructing the foundations of sewers it may be necessary to introduce pilings with capsills and close planking. This is especially necessary in the case of an outfall sewer constructed in unstable ground and liable to be undermined by the action of the sea. When it is necessary to construct pile foundations, experience alone can guide the engineer as to the best mode of procedure in such cases.

## JUNCTIONS WITH SEWERS.

In carrying out works of sewerage one of the most important points for the consideration of the engineer is the proper mode of forming the junctions with sewers.

Junctions in early sewer-work.

In the early sewerage works of this country the ordinary house-drains were usually placed at a level from 18 inches to 2 feet above the invert of the sewer, in order to ensure the drains being kept open or free from the deposit which it was known would surely take place in the imperfectly constructed sewer work of that period; but now that the principle of forming sewers is better understood, and as sewers ought not now to be any longer liable to accumulations of deposit, and as the mode of forming junctions very materially influences the working of a system of sewers, this work should be

Junctions materially affect the working of the sewers.

performed in a proper and scientific manner. It should be laid down as a rule that branch sewers, or drains communicating with sewers, should be made to discharge into the main sewer in the direction of the established current of the sewer, and that the velocity of the discharge of the subsidiary sewers or drains should at least equal that prevailing in the main sewer. Right-angled junctions, both lateral and vertical, have been and are still used for forming the junction with sewers; such junctions, however, have the effect of producing eddies, which check the flow in the sewer, and lead to injurious accumulations of deposit.

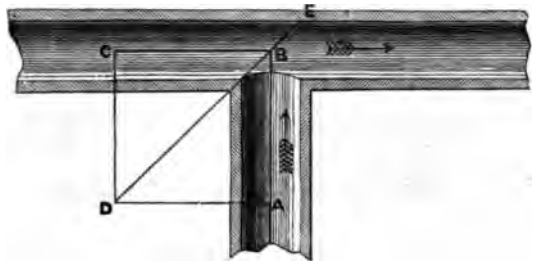
Junctions should join sewers in direction of established current.

Right-angle junctions.

The effects of such a junction may be explained by the parallelogram of forces. In Fig. 45 the line A B

Parallelogram of forces applied to junctions.

FIG. 45.




represents the direction and force of the branch stream, the line C B representing the force or momentum of the stream in the main sewer, by completing the parallelogram A, B, C, D, the diagonal D B will represent the force and direction of the combined current, showing the effect of such a junction would be to cause the stream of sewage to impinge upon the sewer at E, whereby the velocity of the stream through the sewer is diminished as a portion of the velocity or momentum is expended in causing eddies, and experience shows that such eddies lead to the accumulation of deposit above the point of junction, the cause of which is due to the flow from the branch sewer, which has a ten-

Eddies lead to deposit.

dency to cause the sewage to rise at the opposite side of the sewer, or at E, and the continuity of the inclined plane, which should mark the surface of the flowing stream through the sewer, is broken, so that the portion between B and C is less inclined, or may be level, or in some cases may have a fall against its proper head. The consequence of this is that the velocity of this portion of the sewer is materially diminished, and deposit takes place. An examination of sewers, connecting at right angles, shows that invariably a shoal is formed above the point of junction, diminishing in depth as it advances up the stream. Fig. 46 shows a right-angle junction entering

Deposit caused by improper junctions.

Right-angle junction entering the crown of a sewer.

FIG. 46.

at the crown of an ordinary pipe sewer. In this wood-cut the effects are shown by the deposit at A A, which is always greatest on the up-stream side. Fig. 47 shows a junction entering at less than a right angle.

FIG. 47.

Oblique junctions.

It will be seen, by completing the parallelogram A, B, C, D, in this case, that the more acute the angle the less disturbance will be caused by the flow of the branch sewer, as the point E is removed a considerable

distance down the sewer, but with a curved junction, as shown in Fig. 48, which is constructed "by a

Curved junctions.

FIG. 48.

curve tangent to the direction of both sewers, eddies are avoided, and when the radius of the curve is great the diminution of the velocity is almost inappreciable." It is customary in practice, when curved junctions are formed, to give the branch sewer or drain a rather greater amount of fall in the curve, in order to make up for the resistance of the bend. Junctions made at points above the flow of the ordinary water-line in the sewer, even when joining the sewer at an angle, act prejudicially in causing eddies by diminishing the velocity. For example, a junction made in the crown of the arch of the sewer, produces the same effect upon the flow as a junction at right angles; as shown in Fig. 46, because a body of water falling from a height on to the surface of a flowing stream, retards the velocity in the same way as a right-angle junction. The proper position for a junction is within the water-line, but not so low that the flow from it would be checked by the sedimentary deposit that will be rolled along the bed of the sewer. It will be seen that when junctions are so placed that the outfall of a house drain will be below the water-line, the drain will be trapped at its outlet, and therefore the ventilators of house drains cannot judiciously be used to ventilate sewers, and moreover house drains, by reason of the sealing of their outlets, require special means for ventilation, in a manner

Curves in junctions have increased fall.

Effect of junctions in crown of sewer.

Proper position for junctions entering sewers.

Effect of junctions on house drains.

Junctions with brick sewers.

hereafter described.* The junctions between brick sewers, and pipe sewers, or house drains, should be formed by the use of a proper junction block, as shown in position in the sewer in Fig. 49, a section of the block used is shown in Fig. 50.

FIG. 49.

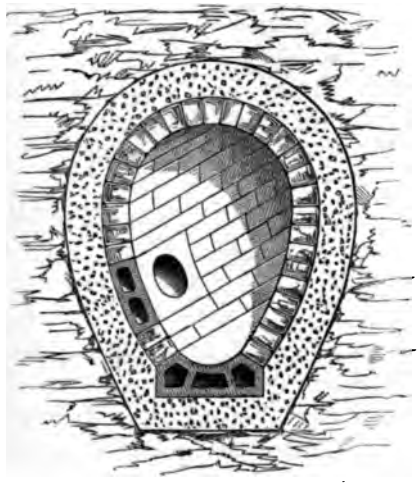


FIG. 50.

These blocks may be built into the sewer as the work proceeds, or may be inserted afterwards. Such blocks are made of fire-clay, or of stoneware, and the branch enters the sewer in an oblique direction, and forms the best mode of terminating pipe sewers or drains with brick sewers; otherwise, where pipes are used to form the junction, it is generally necessary to cut them to fit the brickwork at the proper angle, and in cutting pipes the work is not usually so carefully done but that some imperfection remains, which detracts from the merit of the work. The junctions of pipe sewers, or drains with pipe sewers, when curved, are struck from a centre at right angles with the centre line of the pipe, the inside of the straight pipe meeting the inside of the branch at a tangent on a radius line from which it is struck. Where more pipes than one are required for forming a junction, the end of each pipe should, when manufac-

Objections to pipes in forming junctions with brick sewers.

Mode of forming junctions with pipe sewers.

Form of ends of pipes.

* *Vide* page 230.

tured, be cut to the radius of the curve with which they are described. The greater the radius of the curve used in forming a junction with a sewer, the less will be the resistance offered to the flow, and the more perfect will be the work. Where sewers are laid in straight lines they may communicate at right angles when they discharge into manholes the outlet from which is placed at a lower level than the inlet. This arrangement requires extra fall to be taken at the manholes, in order to secure the advantages of having the sewers laid in straight lines for facilitating the purpose of examination. The junctions between brick sewers and brick sewers, when sewers are of nearly similar size, are formed as shown in Plate No. III., Figs. 7 and 8, which show the arrangement of forming junctions where two or three sewers join with one main sewer. The plan usually adopted is to construct a bell-mouth, which receives the sewer at its largest end, and gradually diminishes at the lower end to the size and shape of the sewer, which will convey the whole volume to be discharged; but where small sewers meet larger sewers they usually join with a curved junction, as shown in the woodcut, Fig. 48.

Great radius of curve the best.

Circumstances under which right angles may be allowed.

Junctions of brick sewers with brick sewers.

Description of Plate No. III.

Use of bell-mouth sewers.

Junctions of small brick sewers.

## FLUSHING ARRANGEMENTS OF SEWERS.

In all works of sewerage it is important that arrangements should be made for flushing the sewers in order to keep them thoroughly cleansed and in efficient working order. It has already been shown that a certain velocity of flow is necessary to prevent the deposit of sedimentary matter in a system of sewers. Now as every sewer has, more or less, an intermittent flow, and in some cases, especially as in that of sewers receiving rainfall, the volume flowing through the

Flushings necessary.

Intermittent flow.

sewer may at times be so small, when compared with the size of the sewer, that such a retardation of the natural velocity may arise as will lead to the deposit of sediment. It is therefore at periods when the flow of sewage is at its minimum, that the arrangements for flushing are most beneficial. The works necessary for flushing sewers have for their object the maintenance, for a sufficient time, of an effective velocity through them, so as to remove any deposit and to cleanse the sewer. This velocity may always be created by the discharge of a sufficient volume of water or sewage through the sewer. In practice it will be found, that it is not necessary, in a well-devised system of sewers, to provide for flushing purposes a volume equal to the full discharging capacity of the sewers, as theoretically a better velocity is provided with a smaller volume, for by reference to Tables 16 and 17, at pages 66 and 68, it will be seen that an oval sewer running two-thirds full, has a greater velocity than the same sewer has when running full. The volume required to get good flushing power is therefore considerably less than the full discharge of the sewers, as will be seen by reference to Table 20, at page 78, which shows the relative areas of the channel, and Tables 22 and 23, at pages 82 and 84, show the relative volume discharged. As an example, a sewer 2 feet by 3 feet, laid at an inclination of one in a thousand, when running full, will have a velocity of 141 feet per minute, and discharge 648 cube feet in same time, while the same sewer running two-thirds full will have a velocity of 148 feet per minute, and discharge only 447 cube feet in the same time. Circular sewers have theoretically the same velocity of flow when running half full as when they run full; and although it may appear paradoxical, there is a point in the flow of all sewers when they discharge more than when running full. Various plans have been suggested and adopted at different times in order to effect the flushing of sewers. Mr. Roe, when surveyor of the

Object of flushing.

Volume necessary for flushing.

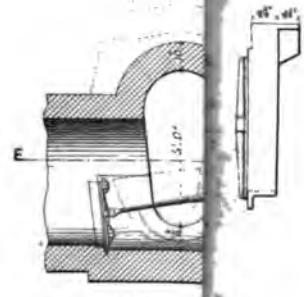
Example as to volume and velocity.

Circular sewers.

Mr. Roe's system of flushing.

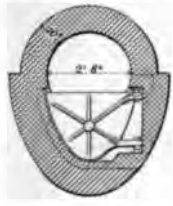
Fig: 2.

Fig: 6.



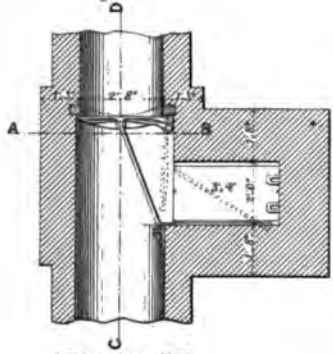

SECTION

Fig: 3.



SECTION A.B.

Fig: 1.




SECTION E.F.

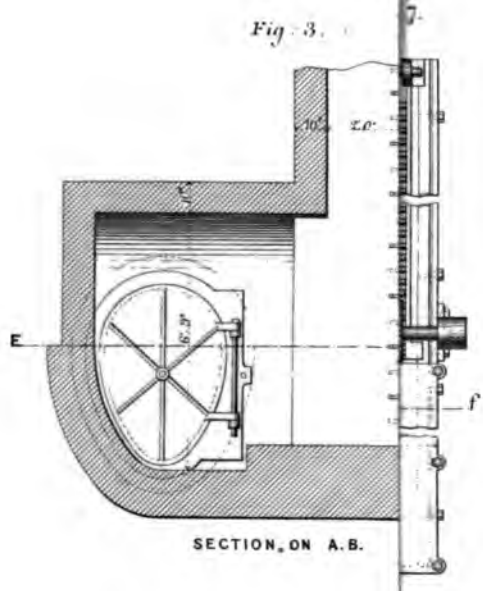
F

Fig 11.

DOR.

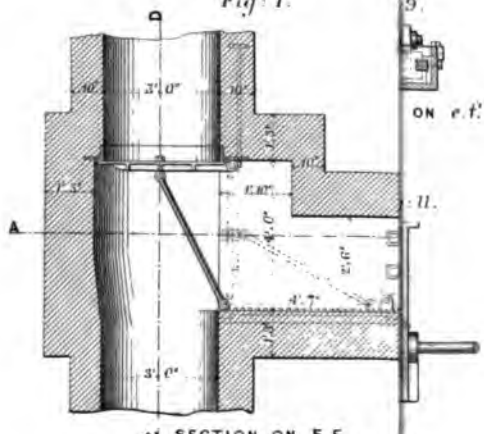
Kell Bros Lith.

*Fig: 3.*




SECTION ON A.B.

*Fig: 1.*




SECTION ON E.F.

Holborn district, introduced the system of damming up the sewage within the sewers, and then suddenly liberating it, so that the ordinary sewage itself became the natural agent for flushing the sewers. Independent supplies of water are now often furnished in such quantities as to increase the ordinary flow, accelerating the velocity to such a degree as to cleanse the sewers. When the ordinary sewage of a town is to be made use of for the purpose of effecting the flushing of the sewers, special flushing gates or sluices are fixed in the sewers, which when used have the effect of damming back or heading up the sewage in the upper reach or section of a system of sewers, and then by suddenly liberating it into the lower reaches the flushing and cleansing of the sewer is effected. Flushing gates are of various descriptions, and may be worked in various ways. They are made as half, three-quarter, and whole gates, just in proportion as they fill the sectional area of the sewer. Some engineers prefer the use of half-flushing gates, as shown in detail in Plate V. Half, and three-quarter gates have this to recommend them, that if the flushing party neglect to remove the dam at the proper time, no serious evil will arise, as the ordinary sewage would escape by flowing over the gate, and pass away into the lower portion of the system of sewers without causing any damage. Whole gates are used when a large volume of sewage is required to be dammed up in order to secure a sufficient volume to produce the requisite velocity in the sewer to render it self-cleansing, and it is advisable to use such gates when sewers of comparatively small size are constructed at small inclination. Such a gate is illustrated in Plate VI. All flushing gates are usually worked by being closed against the current, and when not self-acting are fixed in position by a stay having a cam head working in a cast-iron trough, as shown in Plate V. Fig. 1 in this plate shows the plan with flushing gate fixed across the sewer and

Additional water supplies.

Flushing gates.

Description of flushing gates.

Advantages of some forms of flushing gates.

Whole gates, when they should be used.

Working of flushing gates.

Description of Plate No. V.

Plate No. V.

secured by the stay. Fig. 2, is a section. Fig. 3, front elevation of the gate. Figs. 4, 5, 6, 7, and 11 show the details of the flushing gate and its cast-iron frame. Figs. 8 and 9, details of cast-iron trough. Fig. 10, details of the stay and cam for fixing the gate in position. After the gate is fixed and the sewer is filled to the proper extent, the flushing man strikes the stay upwards, when it slides along the trough owing to the pressure of water opening the gate so soon as the cam is liberated, and the whole of the pent-up charge of sewage is precipitated to the lower reach of the sewer with a considerable velocity. In cases where whole doors are used, and the sewer is running nearly full, to obviate the inconvenience that would arise to men approaching the door, a rack and pinion movement should be provided, which is connected with the flushing gate, and is worked from the street level, as shown in Plate VI. Fig. 1 in this plate shows the plan with the flushing gate fixed in position across the sewer: the stay in this case is attached to a rack that slides in the fixed trough. Fig. 2 shows the section of the gate and stay when fixed across the sewer. Fig. 3, front elevation of the flushing gate. Fig. 4, plan of the shaft, showing in the angle the spindle and ratchet apparatus for fixing the door. Fig. 5 shows mode of guiding and staying the spindle by which the apparatus is worked. Figs. 6 and 7 show a section and elevation of the rack and pinion movement. Figs. 8 and 9 show sections of the trough and rack and pinion movement. Figs. 10 and 11, the details of the ratchet movement for securing the flushing gate in position. This gate is fixed in position with a key from the street level, and when it is shut it is secured by a catch working in a ratchet fixed on this spindle near the street level, the pressure of water on the gate throws the strain upon the spindle, which is kept from moving by the catch before referred to, but so soon as this catch is liberated, the spindle revolves, the rack slides

Flushing gates worked from street level.

Description of Plate No. VI.

back, and the gate opens. Occasionally these flushing gates are connected with a self-acting apparatus, so that they shall open themselves at the proper time, or so soon as the sewer behind the flushing gate has filled to the requisite height. This arrangement is shown in Plate VII. Fig. 1 in the plate shows the plan of a self-acting flushing gate. Figs. 2 and 3, sectional elevations of the same. In this case the door is fixed by the stay A, which is provided with a rule joint shown at X. When the sewage in the sewer has risen to the requisite height, it begins to overflow by the pipe B, and to fill the chamber C, and so soon as the volume in this chamber is sufficient in weight to overbalance the counterweight shown on the same shaft, it falls, and in falling a part of the apparatus strikes the stay upwards at the joint, which when once deflected out of the straight line in which it was fixed, is no longer capable of withstanding the strain upon it, and the pressure of water behind the gates completes the work by causing the joint in the stay to give, and so the gate opens to its full extent. A very simple form of self-acting flushing gate is shown in Figs. 51, 52, and 53.

Self-acting flushing gates.

Description of Plate No. VII.

Tilting flushing gates.

FIG. 51.

Fig. 51, showing plan of gate, Fig. 52, its vertical section, and Fig. 53, its front elevation.

This gate is hinged below its centre, and somewhat resembles a large throttle-valve of a steam-engine. The ordinary pressure of the sewage on that portion of the gate marked A, which is below the hinge or pivot in which it turns, tends to fix the gate in position, but so soon as the sewage rises above the level of the pivot, it relieves the lower portion from pressure, and as the area of the gate marked B above the pivot is greater

Mode of working tilting flushing gates.

Fig. 52.

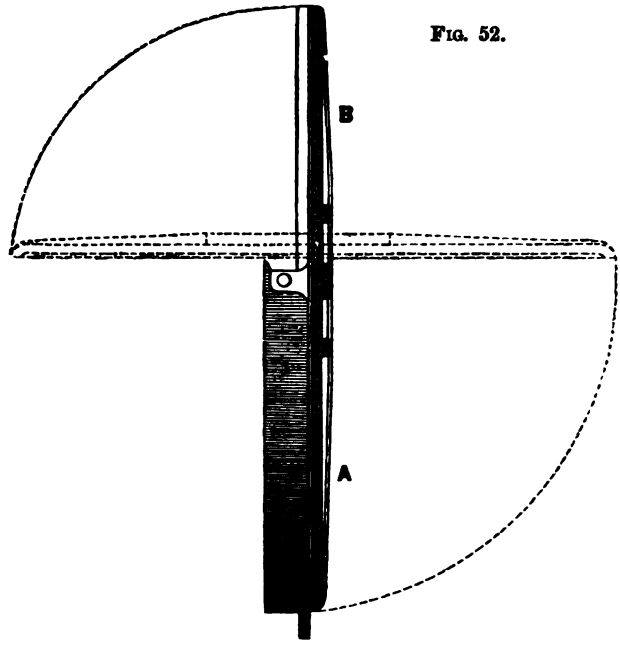
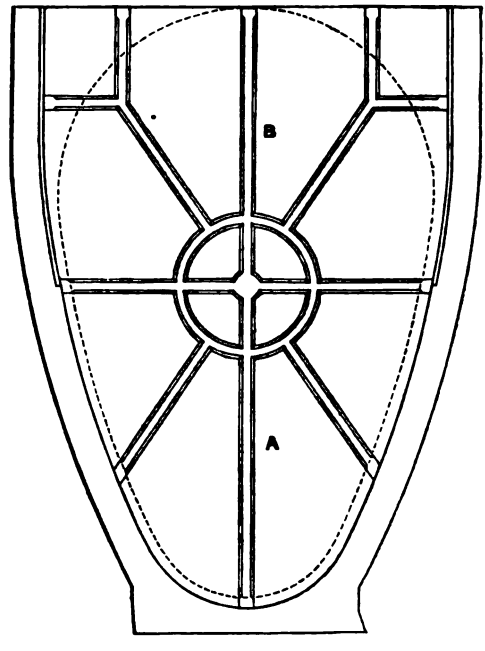



Fig. 53.



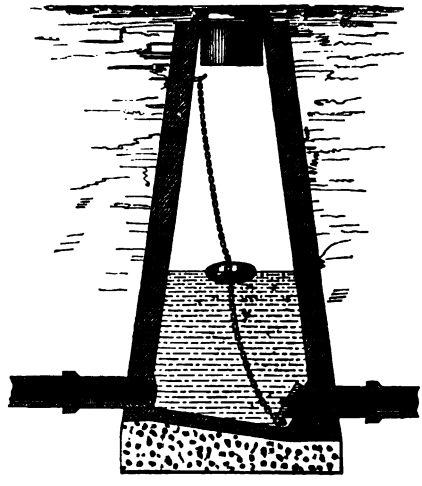
than the area below, a point is reached when the pressure on the upper portion of the gate overcomes the pressure on the lower portion, and the gate tilts and the sewage escapes. The upper portion of these gates being made heavier than the lower portion, when the gate tilts, it falls upon catches provided, and remains horizontally in the sewer, as shown by the dotted lines in Fig. 52. Flushing gates are usually provided with lead seatings and V faces, lead being more durable than any other description of metal, not being so liable to be acted upon by the sewage as other metals. The working parts of self-acting flushing gates should all be bushed and cased with gun-metal, or otherwise they are apt to get fixed in the work. For small sewers the author has used an earthenware flushing block, which is built into the head of every sewer running out of a manhole, as shown at A in Fig. 54.

Seatings of lead.

Working parts should be bushed.

Earthenware flushing blocks.

FIG. 54.



These flushing blocks have a ground face, against which a wooden disk B is placed. The pressure of the water tends to fix the disk in its position, and the disk is connected to a chain, and to guard against neglect the float C is fixed on the chain, so that if the disk is left

Description of block and disk flushing.

fixed in the sewer, so soon as the manhole fills with sewage to such an extent that the float begins to swim by its power of flotation, it liberates the wooden disk from the mouth of the sewer and the sewage escapes to the lower level. The earthenware blocks were introduced on account of their being more durable than metal when in contact with sewage. It is an advantage in a system of sewers to make as much provision as possible for flushing the sewers, but as fixed flushing gates form an expensive item in an estimate, they should be used at long intervals apart, and at all the intermediate manholes grooves should be formed in the brickwork for the reception of boards, so that a ready dam can at any time be formed for flushing purposes. Where flushing arrangements are provided, it is advisable, as a means of security, to provide overflows communicating above the flushing doors with the lower portion of the sewer; so that, if from neglect or accident, the doors remain fixed, the sewers may be relieved of pressure, and the sewage may be allowed to escape without flooding the low-lying portions of the district in which the sewers are located. It may be here noted that the flushing gates which have already been spoken of are not applicable for flushing the upper portions of a sewer, and it is requisite that arrangements should be made for effecting the flushing of the sewers at their upper ends. For flushing the heads of sewers, tanks are usually provided, the contents of which are periodically discharged by means of a plug or valve similar to that shown in Plate VII., Figs. 4 and 5. In some cases where tanks are used at the upper ends of sewers, they are made self-acting, as shown in Plate VIII. Fig. 1 represents the plan of the tank and discharging apparatus. Fig. 2 shows the section of the tank and apparatus with the valve closed, and Fig. 3 shows the apparatus with the valve open. The apparatus acts as follows. So soon as the water rises to a certain level in the tank, it overflows by the

Abundance of means for flushing should be provided.

Grooves in brickwork.

Overflows should be provided.

Flushing gates not applicable for heads of sewers.

Flushing from tanks.

Plate No. VII.

Description of Plate No. VIII.

*Fig: 5.*

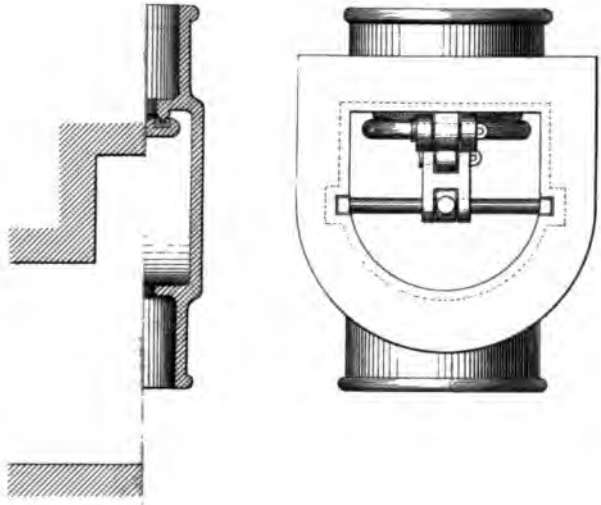
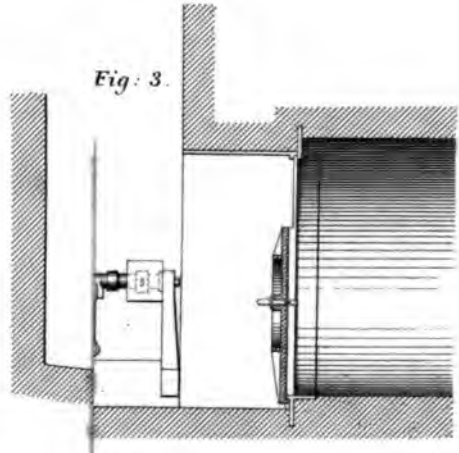


*Fig: 3.*



# FLUSHING TANK.

*Fig: 2.*

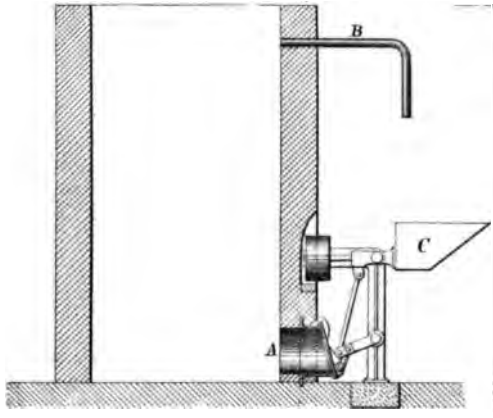



*Fig: 3.*

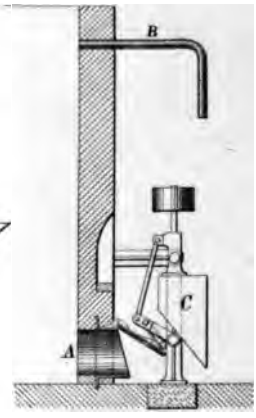
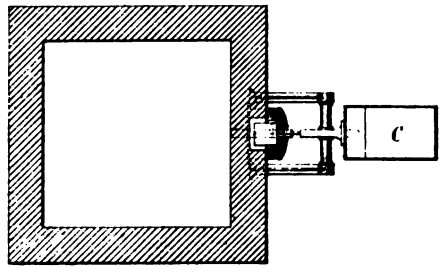



*Fig: 1.*

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Roll, Bros. Lith.

# FLUSHING TANK.

*Fig: 2.*

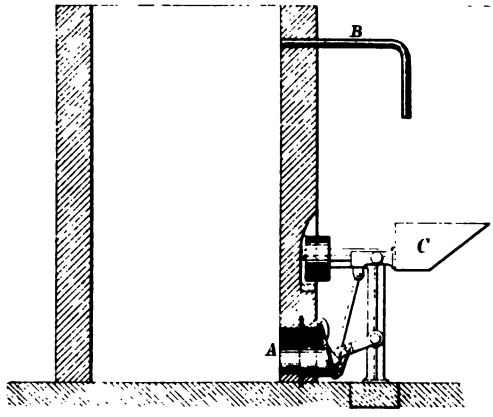



*Fig: 3.*

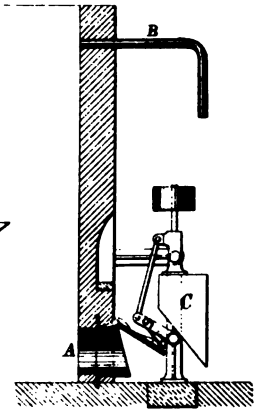
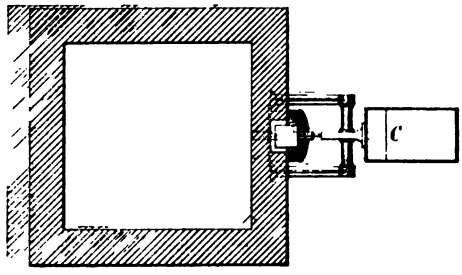



*Fig: 1.*

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# FLUSHING TANK.

*Fig: 2.*

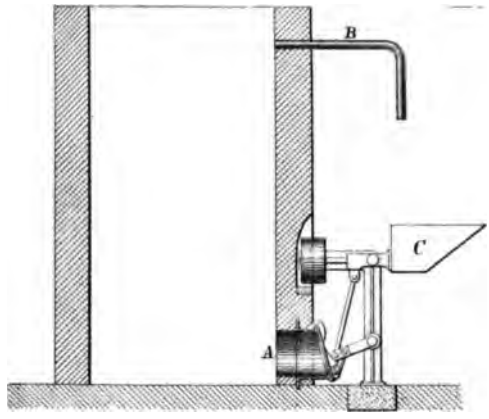



*Fig: 3.*

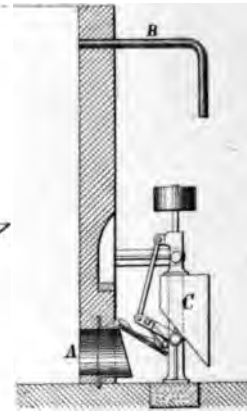
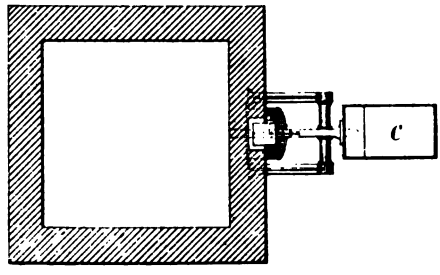



*Fig: 1.*

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Kell, Bros. Lith.

# FLUSHING TANK.

*Fig: 2.*

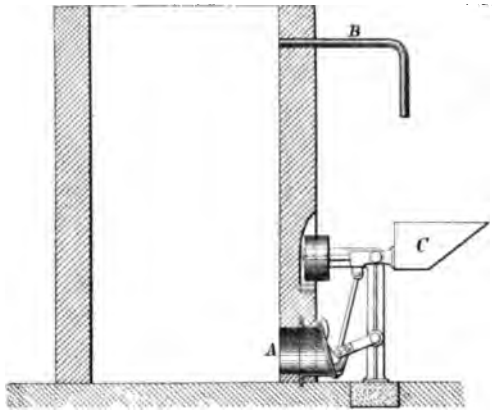



*Fig: 3.*

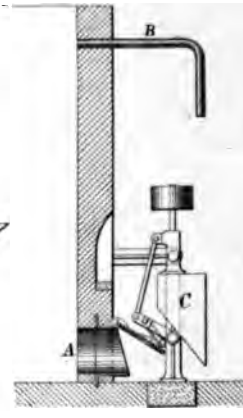
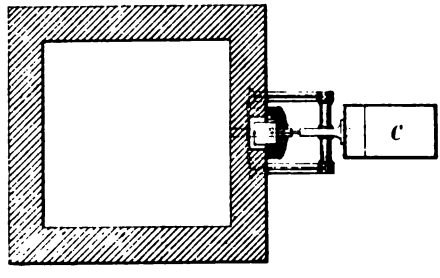



*Fig: 1.*

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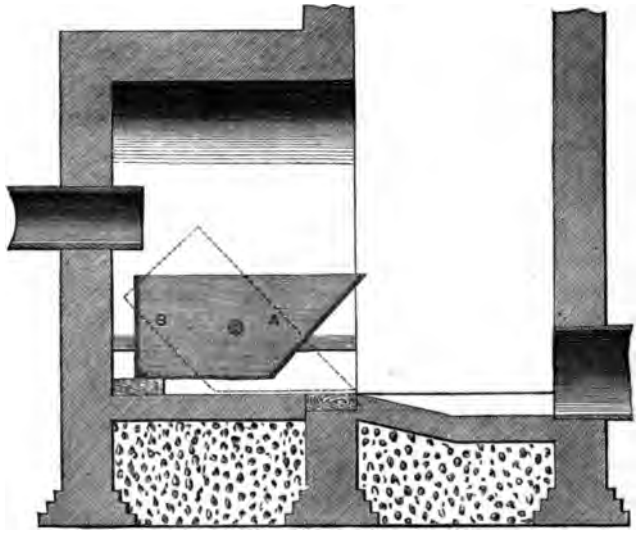
pipe B into the chamber C, and the accumulation of water in this chamber overcomes in time the resistance of the counterweight fixed in the same shaft, when the chamber C falls and opens the valve A and discharges the contents of the tank into the sewer. A very useful tilting flushing apparatus is shown in Fig. 55. It consists simply of a tank moving on trunnions. When

Tilting tank for flushing.

FIG. 55.




empty this tank would remain level, as the portion B behind the trunnion is heavier than the portion A before the trunnion, but when the tank fills with water or sewage the portion A becomes the heaviest, and the consequence is the tank tilts, discharging its contents suddenly into the sewer below, and afterwards righting itself ready to receive a fresh charge. In some districts water is taken direct from the fire-plugs on the water-mains and admitted into the sewers through the lamp-holes or manholes in sufficient quantity to flush the sewers. In other cases special supplies of water are

Special supplies of water.

often provided for flushing, as in the case of Dantzic. The upper ends of some of the sewers are flushed by means of water brought by special pipes from a stream in the neighbourhood, as shown in the general plan of the works, Plate No. I. In this case the water is admitted from these pipes into the sewers by means of a valve closed with a lever and weight similar to that shown in Plate X., Fig. 2. In other portions of Dantzic, as the sewers are constructed at a level below the ordinary water level of the river, and of the streams intersecting the town, water is admitted into the sewers for flushing purposes by means of valves communicating with the river or other streams as shown. Plate X., Fig. 1, shows the plan of the valve. Fig. 2 shows a section of the same. Fig. 3, elevation of front of valve. Fig. 4, the slotted link for opening valve. Fig. 5, the plan showing arrangement of fixing valve. Figs. 6 and 7, elevation and section showing fixing of valve. Fig. 8, grating for protecting valve. In this case the valves are protected by a grating in the front against the entrance of sticks, or other matter liable to choke the sewer. For this purpose a small wooden chamber is made outside the valve, and in the outer framework two grooves are formed similar in construction to an ordinary wooden sluice frame. In each of these grooves a grating, or sluice door, can be inserted at pleasure; the object being, that if the grating gets choked below the water level, another grating can be placed in the spare groove while the other is removed, or a sluice-door may be inserted in the groove in order to enable the valve to be taken out for repair. The operation of flushing sewers should be commenced in the lower portions of the district, and the work proceeded with from the lower to the upper, the sewers in the highest portions of the district being the last to be flushed. In introducing flushing arrangements in which the sewage itself is to form the motive power for flushing, care must be exercised,

Description of valves used.

Description of Plate No. X.

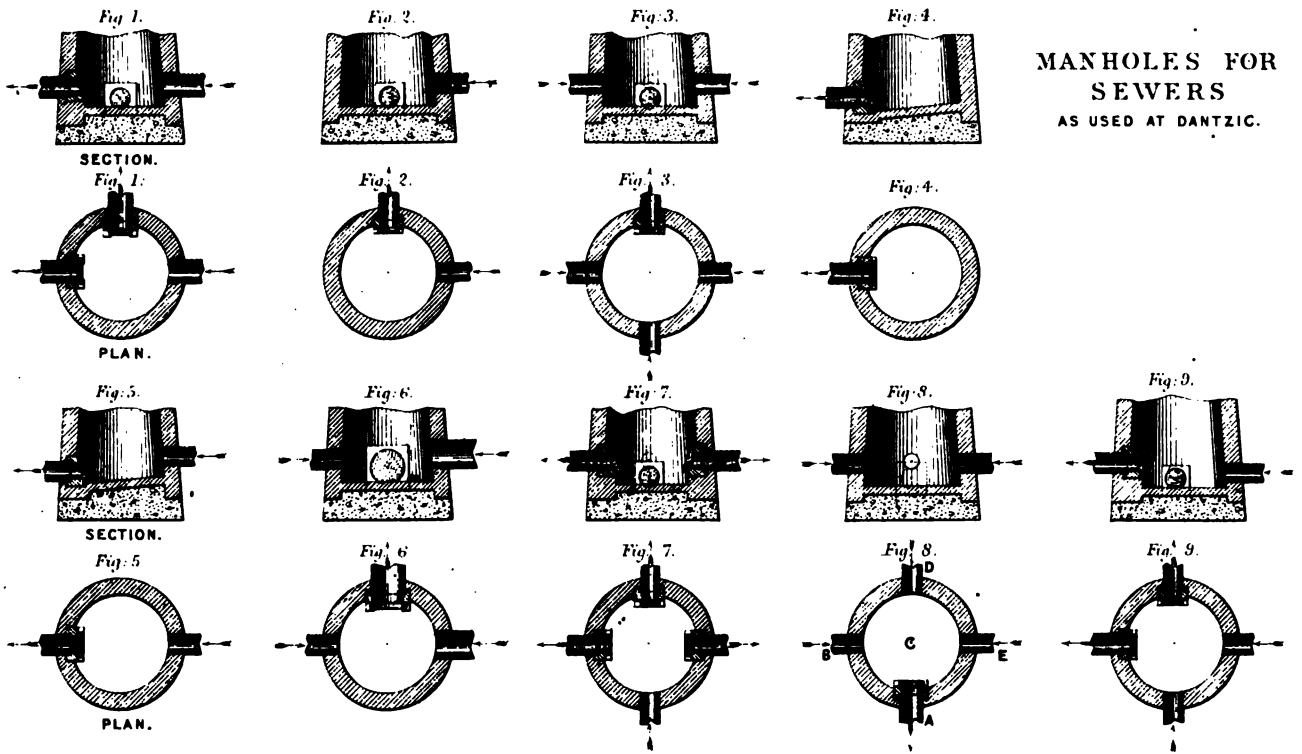
Protection of flushing valves.

How flushing should be conducted.

Sewage must not be dammed up to cause deposit.

# MANHOLES FOR SEWERS

AS USED AT DANTZIC.




London E & F N Spon, 46 Charing Cross Roy. Prof. Lith.

*Fig: 6.*

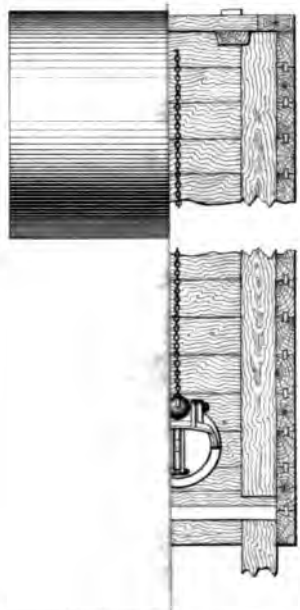
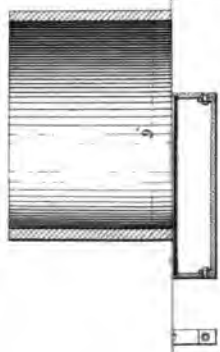
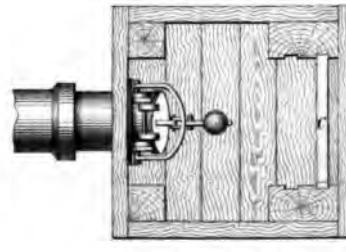


*Fig: 7.*

*Fig: 5.*





otherwise it will be found that the damming up of a volume of sewage for a considerable time will lead to the deposit of sedimentary matter, which, when the flushing gate is open, will accumulate some short distance below it, and for this reason it will be well to combine in the system of sewerage more than one mode of effecting the flushing. Sewers are more thoroughly cleared with pure water than with sewage. The admittance of rainfall into sewers is of considerable value as a flushing agent. In all flushing it is necessary not only to remove the deposit, but also to wash the sides of the sewer free from the mucous matter which adheres thereto, and in which so much lurks that is dangerous to life and health. In periods of epidemic disease flushing of sewers should be frequently practised, and when flushed they may be disinfected with advantage. The advantages and results of flushing sewers were very clearly demonstrated by Mr. Roe, the author of the system, in several reports on the subject. The following extracts are taken from the first report of the "Health of Towns Commission."

More than one system should be adopted.

Value of rain-water.

Removal of mucous matter

Results of flushing.

"Taking it as affording the best approximation that we can at present find, a series of experiments was commenced in order to ascertain what velocity could be obtained in the sewers; and it appeared that deposit might be removed, by the means of dams placed in certain situations to collect heads of water, at less expense than by the usual method.

Mr. Roe's report.

"Another series of experiments was made for the purpose of endeavouring to ascertain the proportion of decomposed animal and vegetable matter, and detritus from the roads, carried through the sewers to the river Thames by the common run of water. Several square boxes were constructed to hold one cubic foot of water each. These were filled with water from different sewers. After allowing the turbid water to clear itself by precipitation, I ascertained the relative amount of

Amount of matter present in sewage.

the precipitate. The following were some of the results:—

| Sewers. | Proportion of decomposed Animal and Vegetable Matter and Detritus from Streets and Roads held in mechanical suspension. | Remarks. |
|---|---|---|
| River Fleet sewer, near outlet | .. 1 in 96 .. | The run of water was 10 inches in depth and 10 inches in width, having an average velocity of 83·47 feet per minute, passing 692·8 cube feet of water per minute; the matter conveyed being 7·21 cube feet per minute, or 103,660 cube yards per annum. |

Fleet sewer.

"The river Fleet sewer conveys the drainage of 4444 acres of surface, or about four-sevenths of the surface of these divisions. That great quantities in addition to the above are carried away by the force of water in rainy weather is certain; allowing this source, and the remaining three-sevenths of the district to only equal the discharge by the river Fleet sewer, there appears to be a quantity of upwards of 200,000 cube yards of matter carried to the Thames, per annum, from these divisions in mechanical suspension, and by the force of velocity, weight, and volume of water. The quantity of deposit taken from the sewers in these divisions, by the prevalent method of cleansing, has averaged about 2200 cube yards per annum; therefore the quantity flushed to the Thames, by the flushing apparatus, is as 1 to 100 of that which was already conveyed by the force of water.

Quantity of matter transported by sewers.

Amount of matter present varies in length of sewer.

"Some experiments were made with the water taken from the sewer at the top and bottom of a long street having numerous courts and alleys on each side. The following is the result:—

"At the upper end of the street matter held by the water in mechanical suspension .. .. .. 1 in 96
"At the lower end of the street .. .. .. .. .. 1 in 39

Proportion of solid matter to water removed.

"In another main sewer, where the run of water is always sufficient to keep it clear from deposit, the pro-

portion was 1 in 80, composed of equal proportions of decomposed animal and vegetable matter, and silt or detritus from roads and streets. In another main line of sewer, kept always free from deposit in a similar manner, the proportion was 1 in 66, the proportion of decomposed animal and vegetable matter being greatest.

"The next experiments were made with the intention of ascertaining what quantity of matter would be carried away (in addition to that held in mechanical suspension) by the transporting powers of bodies of water ponded back and suddenly set in action. The result may be stated as follows, *viz.*—

| | |
|---|---|
| "1st. A two-feet head of water .. .. .. .. | Deposit in sewer composed of soft mud and all descriptions of filth and a little silt. |

"The proportion of matter carried away by the united action of the weight, velocity, and volume of the water, was as 1 to 6½ of water. This was conveyed 2400 feet to a main line of sewer which has a body of water constantly passing through it with sufficient force to keep it always clean; the only signs left of the passage of the loaded water was a discoloration of the sides of the sewer to the height the water of the flush had reached.

Volume of matter transported when flushing.

| | |
|---|---|
| "2nd. A two-feet head of water .. .. .. .. | Deposit in sewer composed of small pieces of brick, stones as large as walnuts, oyster-shells decomposed, animal and vegetable matter, and silt. Proportion of matter 1 in 16 of water. |

"The Commissioners of Sewers for the Holborn and Finsbury division having satisfied themselves of the advantages of a systematic use of flushing in cleansing sewers, have for upwards of three years followed out the principle; the results are such as they anticipated. In carrying out the plan the construction of new sewers with side entrances, and the inserting side entrances to

Flushing proved satisfactory.

old sewers, the forming gully-holes and shoots on a plan that may supersede cleansing as formerly obtained, and the delivery of the water through them in such a manner as to assist the current of water in the sewer, and these and other minor improvements, by the use of which there is a saving effected, are carried on in one comprehensive system connected with the systematic flushing of the sewers.

System of keeping sewers free from deposit.

"The great principle intended to be carried out is, that instead of occasional cleansing as formerly, the sewers should, when once cleansed, be kept free from deposit. The pecuniary saving is, I consider, the least advantage of this mode of cleansing; the great points attained are the avoidance of all accumulations of filth in sewers and the stirring up in removal, and consequent disagreeable effluvia is also avoided; the streets and pavements are undisturbed; the men engaged in cleansing sewers have a more healthy employment than heretofore; private individuals are saved from the annoyance of their drains being choked; and as this plan of flushing affects the health and cleanliness of the inhabitants, the accomplishment of it, on a general and systematic principle, should be deemed of the utmost importance." Again, in reporting at a later period on the question of flushing, he states as follows :—

Advantages of flushing.

Further report of Mr. Roe.

"Your Commissioners some years back constructed a new sewer in Goldsmith's Row, Shoreditch. Prior to letting the contract you directed me to apply to Mr. Beek, the Surveyor of the Tower Hamlets, to learn at what depth a proposed outlet sewer by that Commission would be brought up Warner Place to the junction of the two Commissions; the reply stated a depth of 14 feet 6 inches; and your sewer in Goldsmith's Row was put in accordingly; as, however, the then existing outlet (an open sewer) was several feet above the level of the sewer put in Goldsmith's Row, and as the outlet in Warder Place was not built for several years, an accumulation of foul deposit obtained in Goldsmith's Row

sewer, which it was considered necessary to remove when the new outlet was brought up; an order was therefore given that men should flush the same away. Before the flushing began, the Commissioners of the Tower Hamlets wrote to your Board requesting to be informed when the flushing would take place, and Mr. Unwin, their clerk, told me that the request was made with a view 'to ascertain what deposit from your sewers might be washed into and lodged in the Tower Hamlets sewer.' Openings were made to ascertain the depth of the existing deposits in both lines of sewer, and three men were then set to flush out the Goldsmith's Row sewer with wood dams, &c., which they accomplished in three and a half days; the quantity of deposit in which sewer measured 55 cube yards, and at the former cost of such would amount to 18*l.* 15*s.* 10*d.* When the sewer had been washed out, and a number of flushes of water sent through the Tower Hamlets sewer to ensure the passage of the deposit, I wrote to Mr. Beek to inform him, and to say that on the Tuesday following it was intended to try what effect a flush of water from the Finsbury sewer would have upon the Tower Hamlets sewer on the east side of the Regent's Canal culvert at Rhodeswell Common, a distance of 2 miles and 3 furlongs from the Finsbury flushing gate. The means used and the results were as follows, *viz.*: several square boxes (which we have before used in experiments of this nature), each holding one cube foot of water, were taken on this occasion. Some of these were filled from the common run of water at both ends before the flush was let off, others were filled with the water after the flush had reached the lower end. After allowing the turbid water to clear itself by precipitation, I ascertained the relative amount of the precipitate; the following are the results and particulars:—

Example of flushing.

Flushing with wood dams.

Quantity of deposit removed

Further experiment.

Mode of ascertaining the amount of solid matter in the sewage.

"Distance of sewer at Rhodeswell Common from the Finsbury flushing gate in the Hackney Road, 2 miles and 3 furlongs.

Volume of sewage used.

"Height of flushing gate, 4 feet.

"Quantity of water headed up for one flush, 26,605 cube feet.

"Time required for head to rise varies from 6 to 24 hours.

Proportion of solid matter present.

"Proportion of decomposed animal and vegetable matter, and detritus from streets and roads held in mechanical suspension:—

| | |
|---|---|
| "1st. In the water used for the flush .. .. | 1 in 810 |
| "2nd. In the common run of water at Rhodeswell Common before the flush was let off .. .. .. .. .. .. .. | 1 in 540 |
| "3rd. The proportion of matter in the water when the flush was at the highest at Rhodeswell Common, carried away by the united action of the weight, velocity, and volume of the flush water added to the common run of water .. | 1 in 80 |

Area of waterway.

| | |
|---|---|
| "The sectional area occupied by the common run of water at Rhodeswell Common was .. .. .. .. .. .. .. .. | 3 ft. 1½ in. |
| "The sectional area occupied by the united waters of the flush and common run at the same point was .. .. .. .. .. | 5 ft. 1 in. |
| "The velocity of the current of the common run of water at Rhodeswell Common before the flush .. .. .. .. .. | 95½ ft. in 1 min. |

Velocity of current.

"The velocity of the current, when the flush was passing Rhodeswell Common, 114 feet in 1 minute. The effect of the flush began to be felt at Rhodeswell Common in 1 hour after the head was let off in the Hackney Road, showing a velocity of 209 feet in 1 minute in the covered sewer. For 42 minutes the height of water from the flush gradually increased until it reached the highest point, and it continued at that point for 13 minutes, when it gradually decreased, and in 3 hours' time from the effect being first felt the flush ceased to operate at Rhodeswell Common.

"After deducting the amount of matter held in mechanical suspension by the flush of water before let off, and that in the common run of water at Rhodeswell Common before the flush reached it, there remains the

quantity of 21 cube yards of matter passed from the Tower Hamlets sewers by the use of this one flush.

Quantity of matter removed

" One of your honourable Board then suggested that experiments should be made with bricks to see what distance the flush-water would affect them. This was accordingly done, first with brickbats, and then with bricks. After the first flush had passed, the bat nearest the gate was found to have gone 261 feet, and the farthest 529 feet. By the second flush the foremost had reached 1170 feet from the gate, and the hindermost, with one exception, 670 feet. After the third flush the whole were found to have passed a distance of 1300 feet from the gate. With the whole bricks we had time only for two flushes. After the first flush the nearest brick was 248 feet from the gate, and the farthest was 760 feet distance. The second flush moved the whole of the bricks, the foremost 160 feet farther, and the hindermost 40 feet.

Experiment in removing bricks by flushing.

" The time was now come when the holes were to be opened for taking the depths of the deposit again; the result of which shows that flushing from the Finsbury sewers through the Tower Hamlets sewers does not increase the amount of deposit in the latter, but the contrary; and the result of the particulars taken at Rhodeswell Common evidenced the fact that the extraordinary head of flush-water of the Finsbury sewer in Hackney Road is beneficially felt through the whole of the 2 miles and 3 furlongs of the Tower Hamlets sewer, and doubtless thence to the river Thames."

Benefit of flushing manifest for considerable distance.

## VENTILATION OF SEWERS AND DRAINS.

The evil effects of sewer gas upon public health were known in the ages of antiquity, for it appears from Justinian's Digest, which was completed in the year 555, that, quoting Ulpian, " The Prætor took care that all

Evil effects of sewer air known to ancients.

sewers should be cleaned and repaired, for the health of the citizens, because uncleaned or unrepaired sewers threaten a pestilential atmosphere, and are dangerous."

Roman ventilation of underground conduits.

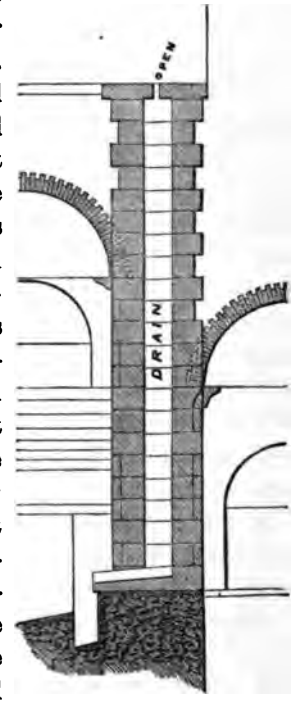
It is also plain that the Romans had a clear knowledge of the necessity of ventilation for underground conduits, as may be seen in the provisions they made in the construction of their aqueducts whenever they passed below the level of the ground. On examining these ancient works, it is found when aqueducts contoured the side of a hill, "putes," or shafts, were sunk, to allow the vapours which arose to be discharged. Many of these shafts were steined, and are still in perfect order. They were constructed at intervals of about 120 feet apart, and served the purpose, not only of ventilation, but of "admitting light or air, and the workmen, also, who were required to repair any defect, or remove any deposit which, by any circumstance, accumulated in the channel"—just in the same way as ventilating manholes are now provided in every modern system of sewerage. The drainage works of the Coliseum of Rome show that the Romans had a very clear knowledge of what was required for the drainage of a large public building. An examination made by Mr. Cresy as to the drainage works of this building shows that the designer introduced works of drainage as an essential feature in its construction. Within its massive walls were formed drains hewn out of the solid stone, or, in other cases, so arranged in grooves cut in the stone work, as to be entirely hidden from view. We also find that provision was made for collecting the sewage and rain-water, and for the prevention of

Mode of preventing vapours entering the building.

the vapours or offensive effluvia from the drains entering the building, for the drains in the outer corridor, which conveyed away the sewage and rainfall, were covered by stone slabs, so arranged as to leave apertures at the sides, the space around being filled in with stone chippings, the drains from the building discharged into the space occupied by these stone chips, and the

liquid entered the sewer after filtering through the chippings. These chippings were covered on the top with a layer of cement so as to prevent moisture or odour entering the building. In Fig. 56 is shown the mode adopted of ventilating the drains, and it should be observed that every descending drain of the entire building is open at its head, and that the head of all the drains of the building terminated in the outer corridors which were open to the atmosphere. It may be here noted in connection with these ancient works that the sewers were used to convey fæcal and other decomposable matter, and that ventilation under such circumstances was an absolute necessity. In the early drainage works of this country the sewers were principally used for the conveyance of surface water, and ventilation was of no material importance; but so soon as sewers were made to convey foul matter, and to communicate directly with the interior of houses, the means of preventing the entrance of sewer gas became a matter of vital importance. The ill effects arising from the non-ventilation of sewers appear after the revival of sanitary science in this country not to have received any marked attention; the reason probably being that towns generally were in so bad a sanitary condition as to make it difficult to separate the causes which led to atmospheric pollution and the propagation of disease. So general were nuisances, and so impure had the air of towns been rendered, it is not surprising to find that,

FIG. 56.




Sewers conveying fæcal matter.

Evils of sewer gas: why not discerned.

until sewerage works were carried out, and the principal nuisances had been abated, the ill-effects of non-ventilation of sewers became apparent. Present experience shows that there is something in the air of sewers that is dangerous to health, and pestilent to life itself, and that it is imperative, by proper ventilation, to dispose of, or neutralize, the effects of its deadly influence.

Sewer gas dangerous to health.

Unventilated sewers dangerous.

It should be laid down as a rule that all sewers must be ventilated, as unventilated sewers are far more dangerous than steam-boilers without safety-valves. The necessity for the ventilation of sewers is clearly shown by the evil effects that have arisen in those districts in which no provision has been made for their ventilation, or, where the arrangements which have been adopted have been imperfect. It is a remarkable fact, but nevertheless true, that from those towns in which no proper provision is made for the ventilation of the sewers, a certain type of disease (typhoid fever) is seldom absent.

Necessity for ventilation of sewers.

Effect of temperature of houses.

The normal condition of the generality of houses has an important bearing on the necessity for the ventilation of sewers and drains. The superior temperature of the air of houses, and the draught caused by chimneys, have the effect of causing the various traps that are used to seal the drains to be relieved from pressure. Consequently, as there is less atmospheric pressure upon traps within houses than upon external traps, and, moreover, as many of the traps used within a house have far less seal than those usually employed out of doors, when no ventilation is provided, gases are sure to escape into houses as the point of least resistance. The evil effects of the want of ventilation were conclusively shown in the early sewerage works of Croydon, in which place, no sooner were the works of drainage drawing towards completion, than the town was visited by an epidemic of typhoid fever, which was traced entirely to the absence of ventilation in the system of sewers. The mortality of Croydon at this period rose from 18·53 per thousand in 1851 to 28·57 per thousand in 1853. These early

Effect of non-ventilation of sewers at Croydon.

Early sewer works of Croydon.

sewer works were designed on the principle that all matters were to be so rapidly discharged from the sewers, and the sewers flushed with such a copious supply of water, that decomposition could not take place, and therefore it was thought that sewr egas would never be present; but in practice this theory was not found to be borne out, and it is a remarkable coincidence as to the cause of the frequent outbreaks of fever in Croydon, which took place at certain intervals until the year 1866, when the sewers were thoroughly ventilated, that diseases which formerly made their haunt in the low-lying districts were transferred, after the completion of the drainage works, to the highest or best portions of the town, thereby establishing the fact that the presence of the disease in the high localities was due to something carried in the air of the sewers, which, in obedience to a natural law, accumulated in the highest part of the district. It may be said that as Croydon was sewered on the small-pipe system, the result of non-ventilation was attended with more marked results than is the case in towns where sewers of larger size are in vogue, as the fluctuation in the rate of flow, and the effect of sudden changes of temperature, which have an extraordinary influence on the air of sewers, in this case exercised a more marked effect in increasing the pressure of the imprisoned sewer air.

Transfer of disease from lower to higher district.

Effect on small sewers.

Result of sewer ventilation.

With regard to the results that have arisen when ventilation of sewers has been adopted, the case of Croydon shows clearly that proper ventilation has been attended with very beneficial results. Since the introduction of systematic ventilation there have been no periodical outbreaks of fever, and the general rate of mortality has so declined, that in a district having a population of nearly sixty thousand persons the rate of mortality rarely exceeds eighteen in the thousand, which is a standard of health unparalleled in the history of sanitary science, for a district having so large a population. The case of London affords another striking

example as to the influence of sewer ventilation. Here the sewers are ventilated, though no general plan is adopted for dealing with the noxious effluvium escaping from the ventilators, and yet London stands at the head of all large towns by reason of its small death-rate, which has been ascribed by more than one eminent authority to the somewhat rude ventilation provided for the sewers.

Theories as to the cause of disease.

There are two theories as to the cause of disease. The first is known as "Liebig's theory," *viz.* that disease is due to organic matter in process of decay, communicating the elements of decomposition. The second is called "Pasteur's theory," which ascribes the cause of disease to organized germs. Organized forms have been found by Dr. Dundas Thompson in the air of sewers, but whether disease is due to the presence of these organized forms or not, it may be laid down as a rule, that in those periods when disease is epidemic, and no ventilation of sewers or drains is provided, the spread of disease is facilitated by the communications which exist through the sewers and drains. Numerous cases of this kind have come professionally under the author's attention. To take one case. In the year 1870, an outbreak of fever occurred in a market town in Kent, and in making an investigation the author found a row of detached houses, in every one of which there was fever, and yet no communication had taken place between the various occupants. Upon inquiry it was found that a case of fever was imported into one of the houses, and the disease rapidly spread to all the others. On investigation it was found that all the houses were drained by one common sewer into a cesspool, no provision was made for the ventilation of the drains, and a branch drain was brought within each house. All the drains were either untrapped or imperfect, so that any gases present in the sewer or cesspool must pass into the houses as the only mode of escape; in fact, the method of draining into the cesspool, as in this case, was

Organic forms found in sewer air.

Disease spread by sewers.

Example.

similar to that of draining into a bottle, all the liquid and solid matter passing into the drains, liberating an equal amount of the foul air, conveying no doubt the germs of disease which escaped into the houses. In the author's experience stoppages in the sewers of a large town, which have had the effect of causing an increase of pressure in the sewer air, have almost invariably been found to coincide with an outbreak of disease in houses which were affected by the stoppage. In a system of unventilated sewers, every house in a district is placed more or less in communication, and as a natural consequence, diseases may be transmitted from house to house by the sewers and drains, as evidenced in the case already referred to. If further evidence were needed as to the ill effects of sewer air, this fact is often forcibly brought to our attention by the loss of the lives of men who are employed to work in our sewers, or in the confined places in which sewage is treated; but it should be here noted that the cause of these deaths can be traceable to the chemical impurities of the air of the sewers as distinguished from that more general impurity which escapes detection, but which is the real cause of disease.

Effects of stoppages in sewers.

In absence of ventilation all houses are in communication.

Loss of life in sewers.

There are some persons who believe that the emanations from sewers are not dangerous, in the sense of producing disease. They base their observations on the fact that the gases which are known to be present in sewers have not been shown to be the means of producing disease. It is true that in a very dilute form some of the gases are innoxious; but it is not so much the presence of gases of known composition that is so injurious, as the organic vapours and germs of disease which are carried in the air of sewers, and which are ever active to feed or spread disease until effectually destroyed. Sewer gas escaping into the streets, and combining with large quantities of atmospheric air, is less injurious than when allowed to escape into the more limited atmosphere of our houses. All the organic

Unbelief in danger of sewer gas.

Dilute sewer air.

Property of organic poisons.

poisons can be diluted to such a degree as completely to palliate their destructive effects; but still they may retain all their poisonous properties when again concentrated. Pure atmospheric air has the power of oxidizing or destroying organic compounds, but when sewer air enters the generality of houses, especially at night, when the house is closed and the whole atmosphere has been robbed of its vital properties, the gas carrying the elements of decomposition or the germs of disease becomes a deadly poison. Sewer ventilation has received, in some quarters, a considerable degree of attention, but its importance is by no means generally acknowledged, nor are works of this class carried out to the extent which is absolutely necessary if the full advantage procurable by the prosecution of sanitary works is to be realized. There are many towns in this country in which no provision has been made for the ventilation of sewers or drains. There are others in which the sewers are but imperfectly or partially ventilated. It is the author's intention in this chapter to point out the nature of the gases found in sewers, the forces at work within the sewers, and to give examples of the various modes that have been proposed or adopted for effecting the ventilation of sewers and drains.

Importance of sewer ventilation not generally acknowledged.

Gases present in sewers.

The gases found in sewers are carbonic acid, nitrogen, carburetted hydrogen, sulphuretted hydrogen, ammoniacal compounds, and fœtid organic vapour.

Carbonic acid.

Carbonic acid, or choke-damp as it is commonly termed in mining districts, is one of the gases usually present in sewer air. It is the result of decomposition, or the combination of oxygen with carbonaceous matters, and is extremely deadly when present in large quantity, and to inhale it in a concentrated form causes instantaneous prostration, followed very speedily by death. In some cases this gas is emitted from the earth when constructing sewer work through decayed matter, or in the proximity of old cesspools, but its principal delight is to haunt unventilated sewers. The deadly lake of

Java, whose borders are said to be strewed with mortal remains, lends its testimony to the destructive effects of this gas. Fresh air or fresh slaked lime will remove or destroy its poisonous effects.

Nitrogen.

The excess of nitrogen present in sewers may be accounted for from the fact that the oxygen of the atmosphere has been used up in entering into combination with certain organic compounds which are present, leaving the nitrogen free. Nitrogen has not been shown to be a poisonous gas, although it will not support animal life.

Carburetted hydrogen

The presence of carburetted hydrogen gas is due in a great measure to the leakage from gas-pipes. Such gas also arises from the decomposition of vegetable matter, and is formed in a manner analogous to that in which marsh gas is produced, spontaneously, in low-lying districts abounding in decomposing vegetable matter. This gas is extremely explosive when mixed with a certain proportion of atmospheric air, on which account it is unsafe to enter sewers with naked lights. As a measure of precaution, all sewers should be lighted with safety lamps when it is necessary to enter them.

Sulphuretted hydrogen.

Sulphuretted hydrogen is a gas which is the product of decomposition. It is found more or less in sewers, being always present in those in which the sewage has assumed a certain degree of putridity. It is distinguishable by its disagreeable odour, and is heavier than ordinary atmospheric air. It has been known to fire in sewers. It is the most poisonous of all the gases of known composition. Experiments have been made with it by various authorities, which show that one of the gas and 250 of the air will kill a horse; one of the gas and 500 of air will kill a dog; one of the gas and 1500 of air will kill small birds; that a rabbit was killed in a few minutes by being placed in a bag of this gas, although its head was not enclosed, and it was free to breathe pure atmospheric air. Numerous deaths have been recorded in past times among the workmen

employed in emptying cesspools in which this gas had accumulated. The destructive effects of this gas can be destroyed by considerable dilution, or, better still, can be readily absorbed by the use of charcoal or some of the oxides of iron.

Ammoniacal compounds.

The ammoniacal compounds present in sewer air are the result of the evaporation and decomposition of the sewage, and are also due to its illimination from the sewage by reason of a rise in temperature.

Fœtid organic vapour.

The fœtid organic vapour, which is more or less present in all sewers, is the most subtle and dangerous matter present in a sewer. Of its exact nature and composition but little is known; either it is itself the cause of disease, or it carries the germs of disease, which float about in the air of sewers, like the fine pollen of flowers which float about in the atmosphere. This vapour or the germs of disease can alike be effectually absorbed and destroyed by the use of charcoal.

Dr. Letheby's experiments on generation of sewer gas.

Experiments made by Dr. Letheby, on the generation of sewer gas from sewage show that a gallon of sewage, containing 128·8 grains of organic matter, when excluded from the air, gave, in "nine weeks, 1·2 cubic inches of gas per hour, consisting of 73·833 of marsh gas, 15·899 carbonic acid, 10·187 of nitrogen, and 0·081 sulphuretted hydrogen." It should be noted that this is the result of a laboratory experiment, and after decomposition has, purposely, been allowed to take place. In a well-constructed sewer the decomposing matter would flow with such a velocity as to prevent stagnation; therefore the period of duration of such matter, in a sewer, is too short to admit of such decomposition as to lead to so large an evolution of gas as shown by the foregoing experiment. When atmospheric air is present in sewers, the gases found are "carbonic acid and nitrogen, with but mere traces of sulphuretted hydrogen." The air in a sewer of the City of London, ventilated and fitted with charcoal for deodorizing the escaping gases, was found by Dr. Letheby to contain

Rapid transit of matter through sewer prevents decomposition.

Gases found when air is present in sewers.

79·96 per cent. of nitrogen, 19·51 per cent. of oxygen, and ·53 per cent. of carbonic acid, with mere traces of ammonia, marsh gas, and sulphuretted hydrogen. Dr. W. J. Russell, in September, 1870, collected the air from the Ranelagh sewer at Paddington, which was ventilated by open shafts of the ordinary London type, and he found that it contained 0·40 per cent. of carbonic acid, 20·79 per cent. of oxygen, and 78·81 per cent. of nitrogen, and when tested for sulphuretted hydrogen, by allowing the air to pass over acetate of lead paper, after five minutes' contact, no discolorization took place. The air of badly ventilated sewers contains much less oxygen than shown in the case of well-ventilated sewers. Parent Duchâtell found that the air of a choked sewer, in Paris, which was not ventilated, and after the sewage had been agitated, contained but 13·79 per cent. of oxygen, pure atmospheric air containing 21 per cent. In the ventilation of sewers, air must be admitted (as a matter of necessity) into all sewers in which men are compelled at times to labour, and in the case of the ventilated sewers of London, chemists are agreed that men may safely labour in them on account of the large percentage of vital oxygen present in the air.

Composition of air of ventilated sewers.

Air of badly ventilated sewers.

An examination of the forces at work within a sewer will show how necessary it is that ventilation should be provided, and, from a study of the forces at work, the engineer will be led to form correct opinions as to what measures should be taken for the purpose of securing perfect ventilation.

Forces at work in a sewer.

Heat is one of the most powerful agents at work within a sewer, and is capable of developing a force which is perfectly irresistible in every unventilated system of sewers or drains. The air of every sewer and house-drain is subject throughout the day to a repeated number of expansions and condensations of the air arising from the admittance of hot or cold water. So great is the force exercised by the air of

Heat.

drains, in expanding under the influence of an increase of temperature, that any ordinary trap is totally inadequate to resist its influence. A very simple experiment will show this. In Fig. 57 is represented a glass flask, corked, and having a bent glass tube (forming a trap) inserted as shown in the figure. Let the trap be filled with water —if the hand is placed on the flask its natural warmth will cause the air within the flask to be heated, and in consequence it will expand with sufficient force to throw all the water out of the trap, although the leg A of the glass tube is several inches long. This flask not inaptly represents the frequent condition of an unventilated house-drain, sealed at its lower end by reason of an extra flush of water in the sewer. The ordinary effect of pouring water into such a drain would be to unseal the traps, as no water could enter without displacing an equal volume of the air of the drain; but, apart from this, assuming that water could enter, and that such water had been used for boiling vegetables, or for any other domestic purpose, and was at a temperature of boiling point, that the normal temperature of the air of the sewer at the time of its admittance was at 50° Fahrenheit, and that by reason of the admittance of a large volume of this hot water the

Experiment as to power of expanding air.

Fig. 57.

Effect of pouring water into drain.

Effect of hot water.

temperature of the air of the sewer was raised to 150°. The effect of this increase of temperature may be calculated from the increase in volume as given in Table No. 40, for the

TABLE No. 40.—Showing the RELATIVE VOLUMES of AIR at VARIOUS TEMPERATURES, as given in Dr. LARDNER'S 'HANDBOOK OF NATURAL PHILOSOPHY.'

| Temperature. | Volume in cube inches. | Temperature. | Volume in cube inches. | Temperature. | Volume in cube inches. | Temperature. | Volume in cube inches. |
|---|---|---|---|---|---|---|---|
| −49 | 834·7 | − 5 | 924·5 | 39 | 1014·3 | 83 | 1104·1 |
| −48 | 836·7 | − 4 | 926·5 | 40 | 1016·3 | 84 | 1106·1 |
| −47 | 838·8 | − 3 | 928·6 | 41 | 1018·4 | 85 | 1108·2 |
| −46 | 840·8 | − 2 | 930·6 | 42 | 1020·4 | 86 | 1110·2 |
| −45 | 842·8 | − 1 | 932·7 | 43 | 1022·4 | 87 | 1112·2 |
| −44 | 844·9 | − 0 | 934·7 | 44 | 1024·5 | 88 | 1114·3 |
| −43 | 846·9 | 1 | 936·7 | 45 | 1026·5 | 89 | 1116·3 |
| −42 | 849·0 | 2 | 938·8 | 46 | 1028·6 | 90 | 1118·4 |
| −41 | 851·0 | 3 | 940·8 | 47 | 1030·6 | 91 | 1120·4 |
| −40 | 853·1 | 4 | 942·9 | 48 | 1032·7 | 92 | 1122·4 |
| −39 | 855·1 | 5 | 944·9 | 49 | 1034·7 | 93 | 1124·5 |
| −38 | 857·1 | 6 | 947·0 | 50 | 1036·7 | 94 | 1126·5 |
| −37 | 859·2 | 7 | 949·0 | 51 | 1038·8 | 95 | 1128·6 |
| −36 | 861·2 | 8 | 951·0 | 52 | 1040·8 | 96 | 1130·6 |
| −35 | 863·3 | 9 | 953·1 | 53 | 1042·9 | 97 | 1132·7 |
| −34 | 865·3 | 10 | 955·1 | 54 | 1044·9 | 98 | 1134·7 |
| −33 | 867·3 | 11 | 957·1 | 55 | 1046·9 | 99 | 1136·7 |
| −32 | 869·4 | 12 | 959·2 | 56 | 1049·0 | 100 | 1138·8 |
| −31 | 871·4 | 13 | 961·2 | 57 | 1051·0 | 101 | 1140·8 |
| −30 | 873·5 | 14 | 963·3 | 58 | 1053·1 | 102 | 1142·9 |
| −29 | 875·5 | 15 | 965·3 | 59 | 1055·1 | 103 | 1144·9 |
| −28 | 877·6 | 16 | 967·3 | 60 | 1057·1 | 104 | 1147·0 |
| −27 | 879·6 | 17 | 969·4 | 61 | 1059·2 | 105 | 1149·0 |
| −26 | 881·6 | 18 | 971·4 | 62 | 1061·2 | 106 | 1151·0 |
| −25 | 883·7 | 19 | 973·5 | 63 | 1063·3 | 107 | 1153·1 |
| −24 | 885·7 | 20 | 975·5 | 64 | 1065·3 | 108 | 1155·1 |
| −23 | 887·8 | 21 | 977·6 | 65 | 1067·3 | 109 | 1157·1 |
| −22 | 889·8 | 22 | 979·6 | 66 | 1069·4 | 110 | 1159·2 |
| −21 | 891·8 | 23 | 981·6 | 67 | 1071·4 | 111 | 1161·2 |
| −20 | 893·9 | 24 | 983·7 | 68 | 1073·5 | 112 | 1163·3 |
| −19 | 895·9 | 25 | 985·7 | 69 | 1075·5 | 113 | 1165·3 |
| −18 | 898·0 | 26 | 987·8 | 70 | 1077·6 | 114 | 1167·3 |
| −17 | 900·0 | 27 | 989·8 | 71 | 1079·6 | 115 | 1169·4 |
| −16 | 902·0 | 28 | 991·8 | 72 | 1081·6 | 116 | 1171·4 |
| −15 | 904·1 | 29 | 993·9 | 73 | 1083·7 | 117 | 1173·5 |
| −14 | 906·1 | 30 | 995·9 | 74 | 1085·7 | 118 | 1175·5 |
| −13 | 908·2 | 31 | 998·0 | 75 | 1087·8 | 119 | 1177·6 |
| −12 | 910·2 | 32 | 1000·0 | 76 | 1089·8 | 120 | 1179·6 |
| −11 | 912·2 | 33 | 1002·0 | 77 | 1091·8 | 121 | 1181·6 |
| −10 | 914·3 | 34 | 1004·1 | 78 | 1093·9 | 122 | 1183·7 |
| − 9 | 916·3 | 35 | 1006·1 | 79 | 1095·9 | 123 | 1185·7 |
| − 8 | 918·4 | 36 | 1008·2 | 80 | 1098·0 | 124 | 1187·8 |
| − 7 | 920·4 | 37 | 1010·2 | 81 | 1100·0 | 125 | 1189·8 |
| − 6 | 922·5 | 38 | 1012·2 | 82 | 1102·0 | 126 | 1191·8 |

TABLE No. 40.—*continued.*

| Temperature. | Volume in cube inches. | Temperature. | Volume in cube inches. | Temperature. | Volume in cube inches. | Temperature. | Volume in cube inches. |
|---|---|---|---|---|---|---|---|
| 127 | 1193·9 | 155 | 1251·0 | 182 | 1306·1 | 209 | 1361·2 |
| 128 | 1195·9 | 156 | 1253·0 | 183 | 1308·2 | 210 | 1363·3 |
| 129 | 1198·0 | 157 | 1255·1 | 184 | 1310·2 | 211 | 1365·3 |
| 130 | 1200·0 | 158 | 1257·1 | 185 | 1312·2 | 212 | 1367·3 |
| 131 | 1202·0 | 159 | 1259·2 | 186 | 1314·3 | 213 | 1369·4 |
| 132 | 1204·1 | 160 | 1261·2 | 187 | 1316·3 | 214 | 1371·4 |
| 133 | 1206·1 | 161 | 1263·3 | 188 | 1318·4 | 215 | 1373·5 |
| 134 | 1208·2 | 162 | 1265·3 | 189 | 1320·4 | 216 | 1375·5 |
| 135 | 1210·2 | 163 | 1267·3 | 190 | 1322·4 | 217 | 1377·5 |
| 136 | 1212·2 | 164 | 1269·4 | 191 | 1324·5 | 218 | 1379·6 |
| 137 | 1214·3 | 165 | 1271·4 | 192 | 1326·5 | 219 | 1381·6 |
| 138 | 1216·3 | 166 | 1273·5 | 193 | 1328·6 | 220 | 1383·7 |
| 139 | 1218·4 | 167 | 1275·5 | 194 | 1330·6 | 230 | 1404·1 |
| 140 | 1220·4 | 168 | 1277·5 | 195 | 1332·6 | 240 | 1424·5 |
| 141 | 1222·4 | 169 | 1279·6 | 196 | 1334·7 | 250 | 1444·9 |
| 142 | 1224·5 | 170 | 1281·6 | 197 | 1336·7 | 260 | 1465·3 |
| 143 | 1226·5 | 171 | 1283·7 | 198 | 1338·8 | 270 | 1485·7 |
| 144 | 1228·6 | 172 | 1285·7 | 199 | 1340·8 | 280 | 1506·1 |
| 145 | 1230·6 | 173 | 1287·8 | 200 | 1342·9 | 290 | 1526·5 |
| 146 | 1232·7 | 174 | 1289·8 | 201 | 1344·9 | 300 | 1546·9 |
| 147 | 1234·7 | 175 | 1291·8 | 202 | 1346·9 | 400 | 1751·0 |
| 148 | 1236·7 | 176 | 1293·9 | 203 | 1349·0 | 500 | 1955·1 |
| 149 | 1238·8 | 177 | 1295·9 | 204 | 1351·0 | 600 | 2159·2 |
| 150 | 1240·8 | 178 | 1298·0 | 205 | 1353·1 | 700 | 2363·3 |
| 151 | 1242·9 | 179 | 1300·0 | 206 | 1355·1 | 800 | 2567·4 |
| 152 | 1244·9 | 180 | 1302·0 | 207 | 1357·1 | 900 | 2771·5 |
| 153 | 1246·9 | 181 | 1304·1 | 208 | 1359·2 | 1000 | 2975·6 |
| 154 | 1249·0 | | | | | | |

Formula for increase of pressure caused by heat.

pressure is inversely as the space occupied. Let V = the original volume of the air of the sewer at its normal temperature, $V^1$ = the volume of the air after its increase of temperature, and P = the original pressure, say atmospheric pressure. 14·6 lbs. per square inch, or to a column of water 34 feet high, $P^1$ = the pressure after the increase of temperature, then we have $V : V^1 : : P : P^1$, whence in the foregoing case we have 1036·7 : 1240·8 : : 34 ft. : 40·7ft., showing an increase of pressure of 6·7 feet head of water was caused by the increase of temperature, which is an amount of force that no trap could resist; hence the necessity for free ventilation. The difference of temperature between the external atmosphere and the internal air of a sewer, is one of the forces at work by which the venti-

Difference of temperature.

lation of sewers is effected. The following Table, compiled by Mr. Wm. Haywood in 1858, shows the difference of temperature between the internal air of the City sewers and the external atmosphere:—

TABLE 41. No.—Showing the SUMMARY of OBSERVATIONS as to the TEMPERATURE of the CITY of LONDON SEWERS. Experiments of Mr. Haywood.

| Time of Year. | Temperature in External Atmosphere in Shade. | | | Temperature in Sewer. | | | Mean Temperature of Sewer. | |
|---|---|---|---|---|---|---|---|---|
| | Highest. | Lowest. | Mean. | Highest. | Lowest. | Mean. | Above External Atmosphere. | Below External Atmosphere. |
| | ° | ° | ° | ° | ° | ° | ° | ° |
| Summer .. | 72 | 55 | 65·04 | 68 | 56 | 61·92 | .. | 3·12 |
| Winter .. | 34 | 30 | 32·37 | 52 | 40 | 43·98 | 11·61 | .. |
| Spring .. | 61 | 46 | 52·46 | 59 | 48 | 52·52 | 0·06 | .. |
| Autumn .. | 68 | 48 | 59·90 | 70 | 53 | 62·97 | 3·07 | .. |
| Average of whole year | .. | .. | 50·24 | .. | .. | 55·35 | 5·11 | .. |

By reference to this Table it will be seen that on the average of the year the internal temperature of the sewers was 55°·35, and the external atmosphere in shade 50°·24; so that, on an average of the whole year, the sewer possessed a temperature of 5°·11 only above that of the atmosphere. In the summer months the average temperature of the sewer was below that of the atmosphere. In the spring the temperature of both sewer and air are equal; while in the autumn and winter the average temperature of the sewer was in excess of that of the atmosphere. During the year 1870 the author, from experiments made at Croydon, found that on 220 days the external air rose to a higher temperature than the highest temperature of the sewage, and on 145 days the highest temperature of the air was lower than the temperature of the sewage. There were 313 days when the external air fell to a lower temperature than the lowest of the sewage, and 52 days when the lowest tem-

Summer temperature.

Spring temperature.

Autumn and winter temperature.

Temperature of Croydon sewage.

perature of the sewage was less than the lowest temperature of the external air. It may be here noted that the temperature of Croydon sewers is pretty nearly uniform during the whole year. This is due to the water supply of the district being taken from an artesian well. In the case of the City of London, the temperature of the sewers in winter was considerably below the mean temperature of the summer months, as the water supply is principally taken from surface streams, which are subject to the same variation of temperature as the atmosphere.

Croydon sewage of uniform temperature.

The next force which will be considered, and which renders a system of ventilation of sewers absolutely necessary, is the varying ebb and flow of the sewage. This ebb and flow of the sewage leaving the sides of the sewers alternately wet and dry, naturally leads to the production of much vapour or sewer gas. The ebbing and flowing of the sewage within all sewers has also the mechanical effect of compressing or dilating the air present in the sewers. According to the law of the diffusion of gases, the pressure is inversely as the space occupied; therefore it is clear that, unless openings are made as outlets and inlets, the natural consequence of the rise and fall of the sewage in the sewer must be to draw in and expel foul air at points out of control. For example, suppose we have a sewer running half full, and that by an increase in the rate of flow it begins to run three-fourths full, the air which originally occupied half the sewer when the sewer runs three-fourths full will be compressed into a quarter of the sewer, and being compressed into half the space it originally occupied, its pressure would be increased by an amount equal to that of one atmosphere, or a column of water 34 ft. in height. Against such a pressure (if the sewers are perfectly air-tight) no traps could resist the effort of the imprisoned air. It may be laid down as a rule that in the main lines of sewer, from morn till noon, sewers are expelling foul air by virtue of the rate of

Force of ebb and flow of sewage.

Production of vapour.

Law of diffusion of gases.

Example.

fluctuation of the flow, and from noon to morn they are drawing in fresh air by reason of the same force being at work. Of course these results are greatly modified by the effect of sudden storms. Sewers discharging into the sea, or into tidal rivers, are liable to be tide-locked twice a day. During the period they are so tide-locked, as they fill up with sewage the sewer gases will be expelled, and when the sewers discharge their contents at ebb-tide, fresh air will be drawn into the system of sewerage. In consequence of this rate of fluctuation, it must be clear that all those propositions which have been made, and which hereafter will be referred to, of making down-cast and up-cast shafts for the purpose of the ventilation of sewers, will prove abortive, for when the sewers have within them a force which at one period naturally expels air, all shafts, whether up-cast or down-cast, will at that period become up-cast shafts, and when the air is drawn into the sewer all shafts will naturally become down-cast shafts. It may be here noted that the rate of fluctuation of flow in a sewer or drain is a very powerful agent in promoting natural ventilation; that is, if sufficient openings are formed in the sewers or drains, air will naturally be drawn in at these openings at one period of the day, and will be expelled at another period. This fluctuation in the flow, which takes place naturally in every sewer or house drain, may be augmented, so as to lead to an artificial filling and discharging of the air of certain sections of a system of sewers. To effect this, self-acting flushing valves may be used, so arranged that certain sections of the sewers would be allowed to fill with sewage at certain periods of the day, and this pent-up sewage should then be rapidly discharged, so that the double purpose of flushing the sewers and of ventilating them would be served.

Sewers discharging into the sea.

Down-cast and up-cast shafts will not act.

Fluctuation in flow may be made use of for augmenting ventilation.

Barometric changes affect the amount of sewer gas present in sewers. The diminution in barometric pressure leads to the escape of gases which are stored in the interstices of the sewage, and favours decomposition.

Barometric change a force.

An increase of barometric pressure enables sewer air to carry a larger amount of the vapour of water.

Vapour of water a force.

The vapour of water may be considered a force within a sewer affecting ventilation, as it gives lightness to the air. At 32° the vapour of water is about one three-hundredth part ($\frac{1}{300}$) the density of air, and at 212° it is nearly half as dense as air; so that at all ordinary temperatures the vapour of water will materially affect the density of the air of sewers.

Wind a force.

Wind blowing over the surface of ventilators in a street has a material effect in changing the currents of air within the sewers.

Effect of position of outfall.

The position of the outfall of the sewers in reference to its exposure to the prevailing winds of a district, has also an effect upon the ventilation of the sewers. If an outfall sewer is open to the prevailing winds, rapid currents of air are produced in the sewers, and which may escape so quickly at the ventilators as not to be under control. On this account every outfall should be protected so as to prevent currents of air entering in uncontrolled volume.*

Protection of outfall.

Friction and leakage.

Friction and leakage both play their part as forces at work within a sewer affecting the general question of ventilation. It may also be noted that sewers may act like an ordinary chimney shaft, especially in those districts in which the fall of a sewer is great; so that, when there is an uniform rate of flow through the sewers, there is a tendency for air to enter the openings at the lower points of the system of sewerage, and escape at the higher points.

Sewers may act as shafts.

Diffusion of gas modifies result.

The law of the diffusion of gas tends to modify the forces at work within a sewer. It also modifies the poisonous effects of sewer air. All gases diffuse themselves through each other (although they may not combine) with a rapidity varying with the respective density of the gases. By this law light gases descend and the heavy gases ascend; the rate of diffusion being inversely proportional to the square root of the

* *Vide* page 295.

density—as, for example: if we have two gases, one of which is four times the density of the other, the heavy gas, in this case, will therefore require twice the time the rarer gas would require to diffuse itself in an equal volume. The laws which govern ventilation are the well-known laws of gravitation, currents invariably being produced by the difference in pressure or weight of different columns of air. At 60° Fahrenheit, and with a barometric pressure of 30 inches, a cube foot of ordinary atmospheric air weighs 538·88 grains; or 13·06 cube feet weigh 1 lb. When the pressure of the atmosphere is equal to 14·6 lbs. to the square inch, as there are 22,570 cube inches in 1 lb. of air, that number multiplied by 14·6 will give the height of a column of air corresponding to the pressure of the atmosphere, or 329,522 inches = 27,460 feet. Air will flow into vacuo with a velocity equal to that which a heavy body acquires in falling a distance equal to the height of the atmospheric column, or with a velocity $\sqrt{2g}\,H$, consequently it would rush into vacuo with a velocity $\sqrt{64{\cdot}4 \times 27460} = 1330$ feet per second. Air flows from one atmosphere into another less dense with a velocity equal to that which would be acquired by a heavy body falling through a space equal to the difference of the pressure represented by the respective columns of air. The differences in pressure are arrived at by noting the differences of temperature, for temperature and pressure bear a constant ratio to each other. Air is dilated $\frac{1}{491}$ part, for every degree Fahrenheit its temperature is raised; consequently a column of heated air being lighter than an equal column of cold air, a difference of pressure exists, or there is a tendency for the cold air to flow into the heated air, or for the heated air to escape with a velocity equal to that which a heavy body would acquire when falling from a height equal to that of the vertical column representing the difference of pressure. A cube foot of air loses 1·097 grains in weight for each

Laws of gravitation govern ventilation.

Atmospheric column.

Velocity with which air rushes into vacuo.

Velocity of air flowing from one atmosphere to another.

Pressure determined by temperature.

Loss of weight of air when heated.

Example.

degree that it is heated. For example, supposing a ventilating shaft 60 feet high and 1 foot sectional area, the difference in temperature between the external and internal air is 150°, then $\frac{150° \times 1 \cdot 097 \times 60 \text{ feet}}{538 \cdot 88} = \frac{9873}{538 \cdot 88} = 18 \cdot 33$ feet, or the height of the column of air that will produce motion, which in this case is equal to a pressure of 1·40 lb. per square foot. In practice a simpler mode of calculation is adopted, for, if we multiply the difference of temperature between the external and internal air by the height of the shaft in feet, and divide the product by 491, it will give the height of the column of air producing motion. The formula fully stated is as follows:—

Formula.

$$v = \sqrt{2g\,H\,\tfrac{1}{491}\,(t - t')}.$$

$v$ = velocity of discharge per second.
$H$ = height of shaft in feet.
$t$ = internal temperature.
$t'$ = external temperature.
$2g = 64 \cdot 4$.
$\frac{1}{491}$ = dilation of gas for 1° Fahrenheit.

Applying this formula to the foregoing example, it will be found that $\sqrt{\frac{64 \cdot 4 \times 60 \times 150}{491}} = 34 \cdot 35$ feet per second, or 2061 feet per minute, which also equals the discharge in cube feet, as the shaft is 1 foot sectional area. This calculation is entirely theoretical, and in practice a deduction must be made for friction. In calculating the discharge of circular ventilation shafts or pipes the following formula, which is used for calculating the discharge from gas pipes, will be found applicable:—

Formula for discharge from pipes.

$$D = \frac{19400\sqrt{d^5}}{\sqrt{s\frac{L}{H}}}.$$

D = discharge per minute in cube feet.
$d$ = diameter in feet.
L = length in feet.
H = pressure in inches of water.
$s$ = specific gravity, air = 1·0.

If this formula is applied to the preceding example, $d = 1 \cdot 13$ foot, L = 60 feet, H = $219 \cdot 96$ inches of air, but as water is 814 heavier than air, = $\cdot 27$ inch of water, then we have as the discharge, Example.

$$\frac{19400\sqrt{1 \cdot 13^5}}{\sqrt{1 \times \frac{60}{\cdot 27}}} = \frac{19400 \times 1 \cdot 357}{\sqrt{222 \cdot 22}} = 1767 \text{ feet.}$$

By this formula the discharge is found to be 1767 cubic feet per minute for a shaft 1 foot sectional area against 2061 cube feet per minute, the theoretical discharge. It may be here noted that the draught of a chimney 250 feet high, with a difference of 200° temperature between the external and the internal air, would represent a column of air = $101 \cdot 78$ feet in height, or equal a pressure of $7 \cdot 793$ lbs. per foot, which is equal to a vertical column of nearly $1\frac{1}{2}$ inch of water. Such a draught, if it could be brought to bear on the ventilation of sewers, would force and unseal all the ordinary traps now in use within our houses. Comparison between theoretical discharge and result of formula. Draught would force all traps.

The ventilation of sewers has often been compared to the ventilation of mines, and the same measures which have been proposed for the ventilation of mines have been proposed over and over again for the ventilation of sewers; but those who have made the proposition have not fully understood the nature of the work to be performed, or of the forces at work within a sewer, which dispel all those beautiful theories of ventilation which have been advanced. A few words of explanation, pointing out the difference between mine ventilation and that required for sewers and drains, may prove of service. Ventilation of sewers compared to ventilation of mines.

The ventilation of sewers, although differing from that of mines, is easy and safe, for only make sufficient openings and the sewers will ventilate themselves. It is very different in the case of a mine, and no greater mistake can be made than to confound the system of ventilation as required in a mine with that necessary for a system of sewers. In the case of a mine it is Ventilation of sewers easy and safe.

Mine ventilation.

usual to have one down-cast shaft and one up-cast shaft, or one set of down-cast shafts to convey fresh air through the workings of the mine; on its way to the up-cast shaft the circulation of the air being kept up by artificial means, so as to secure the proper amount of air which should be admitted to the workings, and the discharge of the vitiated air. In a system of sewers such a mode of ventilation as this would prove entirely inoperative, on account of the peculiar features present in a system of sewers, and on account of the forces which are naturally at work within the sewers, whereby all untrapped openings may at one period of the day become down-cast shafts, and at other periods up-cast shafts, as has already been pointed out in referring to the forces at work within a sewer. A sewer may be compared to a tube perforated entirely throughout its length. The introduction of special means of ventilation similar to that adopted in mines, if it could be brought to bear in a system of sewers, would have the effect of causing powerful currents of air to pass into the sewer from the nearest openings, to the exclusion of any current at all from the more remote openings into the sewers. The modes proposed for effecting the ventilation of sewers after the fashion of mine ventilation are natural, and mechanical, appliances.

System used in mines not applicable to sewers.

Sewer is a perforated tube.

Modes proposed for ventilation of sewers.

Natural ventilation.

Natural ventilation embraces all those modes which cause the air to move by reason of difference in temperature or weight of the respective columns of air. In the ventilation of mines, natural ventilation has hitherto been considered the simplest and least liable to derangement, which is a point of considerable recommendation and importance when it is considered what a vast number of individuals are dependent for their health and lives upon the perfection of the machinery for changing the air within a mine. Some difference of opinion has, however, been expressed amongst authorities as to whether natural or mechanical ventilation of mines is the best system: many persons contend

Difference of opinion.

that greater mechanical effect is produced by a given quantity of fuel, when the power is directed through properly constructed machinery for pumping air in or out of a mine, than when a like quantity of fuel is used in heating a column of air, and so creating a natural current.

Mechanical ventilation.

The mechanical contrivances for the ventilation of mines embrace all those modes or means of producing, by machinery, currents of air, either by forcing air into, or by drawing it out of, the mine. When it is forced in it is called the Plenum system, and when it is drawn out it is called the Vacuum system. The plenum system of ventilation would not be admissible in connection with a system of sewers, as the discharge of air at high pressure into sewers would naturally lead to the forcing of the traps and the escape of the air and foul gases into the houses. The effect of the ventilation produced by drawing air out of sewers has been tried, and the results show that all these arrangements affect a very limited length. In Paris and Antwerp shafts have been tried for the purpose of ventilating the sewers, but the results were not sufficiently satisfactory to admit of their use as a general system for promoting ventilation. Numerous experiments have also been made with shafts and furnaces as a mode of sewer ventilation. In the report of Mr. J. W. Bazalgette, C.B., on the ventilation of sewers, addressed to the Metropolitan Board of Works in January, 1866, some results as to the efficiency and the cost of this mode of ventilation are given. Quoting from evidence given by himself and Mr. Haywood before a Parliamentary Committee in 1858, which is here reproduced, Mr. Haywood said, "A down-draught, so complete as to be superior to the diffusive power of the gases, you cannot start with a velocity of less than two miles an hour; and suppose the whole district has been so arranged as to have a sufficient exhaustive power, the mere opening of a water-closet, or the enlarging or the putting in of a new drain into a sewer, or

Plenum system.

Vacuum system.

Effect of ventilation by drawing air out of sewers.

Experiments with shafts.

Messrs. Bazalgette and Haywood.

Cases of derangement of ventilating apparatus.

the making a hole a foot square, or a servant taking up a bell-trap in a sink, or a sewer man lifting a side-entrance covering, would very much destroy the power of the furnace, and unless you had a gigantic power sufficient to guard against all these casualties the system could only be a failure." Mr. Bazalgette, in his evidence before the same Committee, says, "A furnace ventilating any large district would require to produce a very large volume of air, and to keep up a velocity sufficient to ventilate all the branch sewers, and the drag would consequently be so great through the main that it would force open any house-drain traps or water-traps we could form before it would influence the remote branches; but, putting those difficulties out of the question which appeared to us insuperable, we found that the consumption of coal to extract the required quantity of air, supposing that the sewers could be laid out like the channels of mines, would be something enormous." Speaking of the ventilation experiments with the clock tower of the Houses of Parliament, he says, "I found that the furnace of the clock tower of the Houses of Parliament was supposed to have been connected with the adjoining district to the extent of about a quarter of a square mile, and with about six miles and a half of sewers in length when added together, but that the ventilation had in reality been intercepted by a flap, so that the benefit supposed to be derived therefrom was purely imaginary. . . . Having come to that conclusion, the next thing I directed my attention to was, supposing the whole of the air extracted by that furnace was produced from the sewers, and supposing that all the intermediate channels could be stopped, and that it could be directed from the most remote ends of each of the sewers and distributed over those sewers with the most perfect theoretical accuracy, so as to have a uniform current passing throughout each of the sewers towards that chimney, still the effect upon those sewers would be nothing; and the way in which I prove my

Furnace ventilation.

Experiment: Clock Tower, Houses of Parliament.

statements is this: the total area of the 6½ miles of sewers now connected with the furnace is 713 ft.; the total area of the channel through which the air has to be brought from them is 8 ft., that is, about the 90th part of 713; the air was passing at the rate of 542 ft. per minute through the 8-ft. area. Therefore if I could divide that over the whole district, the velocity in all those sewers would be 6 ft. per minute, or $\frac{1}{15}$th of a mile per hour. But we have shown already that there exist in the sewers from other causes velocities amounting to 100 ft. per minute and upwards; and 6 ft. per minute is, practically speaking, stagnation and not ventilation." He further stated, that "supposing you could obtain theoretic perfection, and all the air produced by this furnace was spread through this district, you would only then get up a velocity of $\frac{1}{15}$th of a mile per hour, which is no ventilation whatever. But I have gone farther with the inquiry. Whilst we were making our observations, on Tuesday, the furnace, being kept up, was consuming at the rate of eight chaldrons of coke per day; but I will assume that the defective arrangements, that is, the chimneys being stopped up, the circuitous connections, and so forth, necessitated a very much larger consumption of fuel to produce the same effect than could be produced with better arrangements with a less quantity. I will assume that four chaldrons of coke per day, or half the quantity actually used, would produce that current of air, and that when produced it would effectually ventilate the 6½ miles of sewers, which I think I have shown to be impossible; but supposing it were possible, then I find that for 1500 miles of sewers 230 such furnaces would be required, and the cost of the coke at each of those furnaces would be 876*l.* per annum at four chaldrons per day, . . . . giving a total for the whole ventilation of the metropolitan sewers of 201,480*l.* per annum upon the consumption of coke, without any labour or incidental expenses. The prime cost of those 230 chimneys and

Velocity caused by ventilating shafts.

Velocities found in sewers.

Consumption of fuel.

Cost of furnace ventilation.

furnaces and establishments I have put down at 2000*l.* a piece; that would give 460,000*l.*, or half a million of money." In the same report it is stated that in 1858 he "visited some of the best ventilated coal mines in the North of England and in South Wales, with a view, if possible, to the application of some more perfect system of ventilation to the London sewers. I entered carefully into the comparative advantages of ventilating fans and furnaces, and into the expenditure of fuel requisite for the extraction of a given quantity of air under various conditions. But I found that whilst it was not difficult to conduct a current of air through the continuous passages of a mine having but one inlet and one outlet, and a tolerably uniform sectional area, I found that such a system could not be applied to sewers.

Relative area of sewer and its branches.

The areas of the branch sewers discharging into any one main sewer are, probably, much more than a hundred times its capacity; therefore, even supposing it were possible that they could be all hermetically sealed at all points excepting the extreme ends, a velocity of current equal to 100 miles an hour (which is next to impossible) would have to be obtained in order to secure a current of one mile per hour in each of the branch sewers. But it is not possible to obtain such a condition of things; and this difficulty lies at the root of all proposed modes of ventilation, by extracting the foul gases by furnaces, fans, or such other appliances."

Mr. H. Austin's Report, 1849.

Mr. Henry Austin, the consulting engineer to the Commissioners of Sewers, reported, in 1849, on some experiments that had been made with a view to remove a local nuisance arising from sewer gas by means of furnaces, and as to the advisability or not of trapping the openings in connection with the sewers, he said, "In September, 1848, the sewer in Friar Street, since rendered so notorious, being then, as now, charged with dangerous gases, Mr. Roe and myself joined in a recommendation of Mr. Phillips to try the experiment of drawing off the foul atmosphere from that spot by means of fires, leav-

ing the question of any chemical objection which may exist to such a process to those more adequate to pronounce an opinion upon it. Further experience and consideration have led me to the conviction that whatever local benefit, as in the case of Friar Street, might be derived by such a method, even if it could practically be adopted as a system, the results would be far from satisfactory." The conclusion arrived at by persons well acquainted with the working of a system of sewers is almost unanimous with regard to the inapplicability of a system of mine ventilation to be applied to sewers, while all agree that there may be some special cases in which a partial adoption of such a system may be attended with advantage.

Furnace ventilation not satisfactory.

A glance at some of the propositions which have been made, either for the purpose of preventing the formation of sewer gas, or for the purpose of ventilating sewers and the destruction of the gas, will not be without interest. It has been already stated that the early sewer works of this country were intended for the purposes of leading away rain and subsoil water from the sites of our houses, and as a natural consequence the openings, such as street gullies, into the sewers were left untrapped; but when the sewers began to convey fæcal and decomposing matters, the gases generated were discharged by the gullies. The nuisance of the noxious effluvium escaping from these gullies was so great that it became necessary to trap them. The effect of trapping without ventilation brought its own train of evils, which, in the case of London, led to the adoption of a system of ventilation. Ventilating openings communicating with the sewers were formed in the centres of streets, which had the effect of removing the point of escape of the sewer air farther from the passenger traffic and from the houses, and of aiding the dilution of the escaping gases; but the palpable nuisance of the escaping gases from the openings made for ventilation was the ultimate cause of a vast amount of attention being paid to this special

Proposals made for preventing formation of sewer gas.

Trapping of gullies.

Open ventilators.

subject. Various suggestions have been made for dealing with sewer gas, or for the purpose of preventing its formation. Of the various expedients which have been proposed to prevent the emanations arising from sewers, one of the most common was that sewers should be so constructed as to maintain through them such a high velocity that all matters liable to decomposition should be conveyed with such speed that no time would be allowed for decomposition and the escape of noxious gases. The failure of this theory at Croydon has already been referred to, page 199.

High velocity of transit.

Deodorization of materials passed into sewers.

It has been proposed to deodorize or disinfect all materials previous to passing them into the sewers, in order to pickle or stay the period of decomposition, and so prevent noxious effluvia arising during their transit through the sewers. To attempt to deodorize all matters which are passed into sewers would prove an extremely expensive operation, and those who are acquainted with the general habits of a town population know full well that to enforce a system of general disinfection of materials passed into sewers would be an impossibility.

Deodorization of sewage by chemical agents.

The deodorization of the sewage, as it flows through the sewers, by various chemical agents, has been proposed, in order to prevent the formation of sewer gas. This plan has, to some extent, been tried, but with no material advantage. The fluctuation in the flow of the sewage itself is an element which renders it difficult to apportion the proper amount of disinfectant to the volume of sewage which may, for the time being, be flowing through the sewers; and as every system to be successful must embrace not only the sewers but the house drains, this system of deodorizing the sewage proper of the sewers, leaving the house drains untouched, would only palliate, and could not entirely relieve, any district from the effects of undeodorized sewage.

Causes of failure of deodorization of sewage.

Absorbing materials within sewers.

It has been proposed to place within sewers materials which would absorb the sewer gases as they were generated.

Introduction of chemicals to destroy sewer gas.

Certain chemical agents have been introduced into sewers to give off gases which destroy the noxious properties of the sewer gas.

Charcoal.

Charcoal was applied at an early period within sewers so as to absorb the foul gas.

Pipes within sewers.

It has been suggested to lay within the sewers pipes for the purpose of discharging chlorine or other gas, which should be specially manufactured for the purpose, and on being liberated would destroy the noxious properties of the sewer air.

Electric and galvanic agents.

Electric and galvanic agency has also been proposed as a means of destroying the noxious properties of sewer air. A patent was taken out in 1858 by Mr. John Chisholm, having for its object the use of these agents. The inventor states, "The application of electricity or galvanism to the vitiated and noxious gases contained in confined places, produces effects analogous to those of ozone, acting naturally on matters exposed to its influence in situations where atmospheric air has free access and circulation, but as this natural action is neutralized or destroyed in localities where free access of atmospheric air is prevented, as in crowded towns and structures, drains, sewers, and other confined places, I propose to apply electric or galvanic agency to them and their contents, and thereby produce or disengage ozone; and this agent, which is absorbed almost as rapidly as produced, destroys with it a quantity of deleterious and vitiated gases, and the electric or galvanic action being exerted continuously, ozone is formed as rapidly as it became absorbed; or electricity or galvanism may be so applied as to burn the vitiated gases, and thereby decompose, disinfect, and destroy them."

Chemical agents must be combined with ventilation.

A slight amount of consideration will show that all those agents which have been proposed to be applied in the form of gas in order to destroy the noxious property of sewer air must be combined with ventilation, in order that after combination the resulting

products may be discharged, or otherwise the air within the sewer would acquire such a degree of tension as to force a passage at some point into the adjacent houses. It is clear that those who have proposed many of these methods of preventing the formation or destruction of sewer gas, could not have been acquainted with the real nature and property of the gas, nor with the forces which are at work in every system of sewers. All those plans which relate to the introduction of chemical agents, or the insertion of pipes to discharge gases into sewers, would be liable to be disarranged in the first storm, when the sewers would be flooded. Many sewers, moreover, are of so small a calibre that no room could be found for the insertion of pipes and other receptacles which would be required to be inserted at frequent intervals. No one of these propositions for defecating the air of sewers would render their ventilation less necessary. At the same time, there can be no doubt that many of the agents proposed to be used would considerably modify the poisonous products of the sewer air. All those propositions that have been made with a view to deodorize sewage and prevent the formation of sewer gas would be entirely inoperative in practice, because it has already been mentioned that the ebb and flow within the sewers cause the sides of the sewer to be alternately wet and dry, exposing a large evaporating surface, from which foul vapour is constantly given off, and this vapour passing into the air of the sewer forms sewer gas. Moreover, it must be admitted that, as contact with foul matter will pollute those that touch it, so air brought into constant contact with the foul matters conveyed by sewers will contract impurities, which will be increased by the organic vapours constantly being given off by sewage, and in some cases by organized germs found floating in the air of sewers. In the ventilation of sewers and drains, the essential points to be kept in mind are :—1st. That the system

Sewers of small calibre.

Defecation not render ventilation not necessary.

Reasons why deodorization of sewage fails.

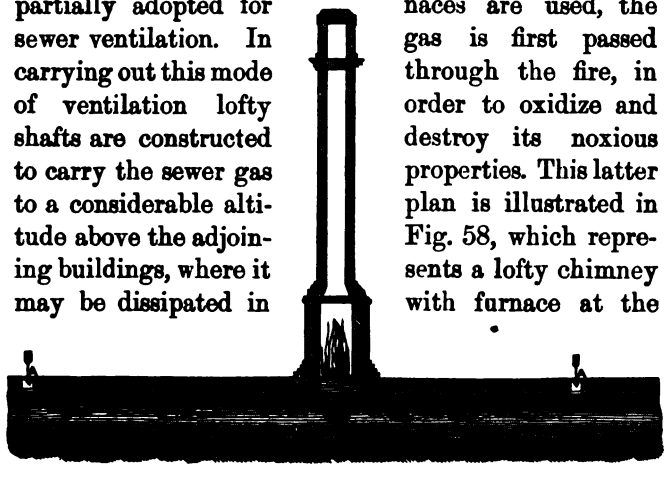
Points to be observed in carrying out sewer ventilation.

shall be simple in its operation and not likely to get out of order, and that it shall be independent of uncertain mechanical aid. 2nd. That it shall admit of the expulsion of all sewer air and the supply of fresh air at all periods. 3rd. That the escaping gases shall be so diluted with atmospheric air as to be rendered harmless, or that they shall be destroyed or arrested. 4th. That the system shall not impede natural ventilation. 5th. That it shall not be costly in execution or maintenance.

Various propositions have been made or have been brought into operation, in order to secure the ventilation of sewers, and in noticing such projects, it will be well to fully consider their merits and defects. Project for ventilating sewers.

Of all the propositions that have been made, the use of lofty shafts of various kinds, sometimes aided by artificial heat or mechanical apparatus, as in mine ventilation, has been by far the most general, and this system has been partially adopted for sewer ventilation. In carrying out this mode of ventilation lofty shafts are constructed to carry the sewer gas to a considerable altitude above the adjoining buildings, where it may be dissipated in the air, or when furnaces are used, the gas is first passed through the fire, in order to oxidize and destroy its noxious properties. This latter plan is illustrated in Fig. 58, which represents a lofty chimney with furnace at the bottom, which can only be supplied with air from the sewers with which it communicates. Shafts without furnaces would not materially influence the ventilation of sewers, as they would exercise but feeble power in Shafts. Shafts with furnaces. Shafts inoperative at certain seasons.

Fig. 58.



producing currents, as will be seen on reference to Table No. 41, page 209, for the temperature of sewers at certain seasons is such that they would be entirely inoperative, on account of the heat of the external air being greater than that of the internal air of the sewer. Thus, at periods of the year when ventilation is most required, as in the summer months, the variation between the internal and external air is so extremely slight, that for all practical purposes these shafts would be perfectly useless, and the feeble currents that would be produced at other periods would only affect the sewers for a short distance from the shaft.

Use of chimney shafts of manufactories.

A very common proposition, and one which has been largely advocated, and to some extent put in practice, is to make use of the chimney shafts of manufactories; but objections are raised to this method by the manufacturers, for the connection of the sewers with them materially interferes with their efficiency as chimneys, and must lead, if universally adopted, to the construction of larger shafts than requisite for the purpose of manufacture. Assuming this system to be perfect in itself, the ventilating apparatus being in private hands, no control could be properly exercised by the authorities in regulating the amount of air that should be passed into the shaft or through the furnace. Again, as these shafts would only be efficient as ventilators when the fires were burning, when the establishments were not at work, as on holidays, unless the furnaces were kept lighted this plan of ventilation would be very irregular.

Objections to system.

Cases in which shafts are used.

In some cases the partial ventilation of sewers, or sewage tanks, is effected by connecting them with the furnaces. This is done at most sewage pumping stations, and the operation is effected by closing the front of the ash-pit of the furnace and making a connection between the sewers and the under-side of the fire-grate, so that all the air for supplying the furnaces must be taken or pass from the sewers. There is some danger in ventilating sewers by furnaces, as the

Danger of connecting sewers and furnaces.

experience with some of the London sewers will show. Take as an example the case of the Friar Street sewer,* which has been already referred to, and which for the purpose of ventilation was connected "with the furnace of a soap factory, a jet of fire burst from the connecting pipe and caused an explosion in the sewer." Of course this was an exceptionally foul sewer, and the introduction of a system of general ventilation would so modify the air of sewers as to render the accumulation of combustible gases an impossibility, except at such times when there was an extensive leakage of gas from the gas mains of the district. It has been suggested by Mr. Peter Spence that the sewers of a town should be used not only for the purposes of sewerage, but as flues for conveying away the products of combustion from the fires of our houses and the furnaces of manufactories, the gaseous products in this system thus being led to gigantic chimney shafts; and by this method it is contended that the sewers and drains would be ventilated. The smoke and gases produced in the process of combustion of our coal fires would combine with the sewer gases and destroy their noxious quality, and the resulting compound would ultimately escape with the smoke and heated vapour by the shafts.

Mr. P. Spence's system of combined sewers and flues.

Special pipes, usually made of metal, have been used for the ventilation of sewers and drains. They are connected with the crown of the sewer, and carried under the roadway and up the external walls of the adjoining houses. One objection to the use of these metallic ventilating pipes is that in cold weather, when the sewers have such a temperature as to produce a natural tendency to discharge their gaseous contents into the air, the vapours ascending by these long metallic tubes become so chilled as to condense the aqueous portion, and check the natural tendency of ventilation. Such pipes may be used in many places

Special pipes.

Ventilating pipes recommended for house drains.

* *Vide* page 221.

with advantage, and especially in connection with the ventilation of house drains, as they will act efficiently for the purpose of allowing air to escape when it becomes compressed, as for example, when any water is passed into a sewer or drain, for it may be taken as a rule that every drop of water poured into a sewer or drain causes the displacement of an equal amount of the foul air of the sewer, and in a system of sewerage the same volume of water may be made to displace several times its volume of sewer air. The use of ventilating pipes in connection with house drains is hereafter further considered at page 266.

Ventilation by lamp columns.

Several suggestions have been made from time to time in reference to the use of the lamp columns in our streets as ventilators for the sewers. Some persons have suggested that the ventilation should be aided by the combustion of gas; others, that the lamp columns should be simply used as ducts for conveying away the gas.

Liverpool mechanical sewer ventilator.

It has been proposed to supplement the ventilation by special pipes with mechanical agency; and in Liverpool, a large number of ventilating pipes have been fitted up with cowl heads and Archimedean screws, for the purpose of exhausting the air from the sewer. The apparatus used is illustrated in Figs. 59 and 60.

When the wind blows it causes the cowl head to revolve, which gives motion to the screw shown in Fig. 59, and the action is supposed to be to withdraw the sewer air; but a slight amount of calculation will show that such an apparatus will oftener be driven by the escaping sewer air than it will withdraw air from the sewers, and therefore it more generally acts as an impediment to ventilation rather than an aid to it. Mr. Philips proposed to use the mechanical effect of the sewage to work fans to extract the air from sewers.

Sewage used to drive ventilating fans.

Steam-jet.

The use of the steam-jet was proposed by Sir G. Gurney, in combination with properly-constructed shafts for the ventilation of sewers. The action of the

steam-jet is due in a measure to the rarefaction of the air, the partial vacuum created, and to the velocity of the escaping vapour, which drags along with it the

FIG. 59.

FIG. 60.

sewer air. The efficiency of the steam-jet for the purpose of promoting ventilation was fully tested some years ago by Mr. Nicholas Wood, and he stated, in a paper read by him when President of the North of England Institute of Mining Engineers, that "In conclusion, the practical result of all these experiments is, that within the limits or range of furnace ventilation, the steam-jet acting as a substitute is attended with an increase in the expenditure of fuel of nearly 3 to 1, without any corresponding advantage either in the steadiness, security, or efficiency of ventilation. On the contrary, from its simplicity of construction, the steadiness of its action, its less liability to derangement, its economy, and its efficiency in cases of emergency, the furnace is more secure, more safe, and a more eligible mode of ventilation than the steam-jet."

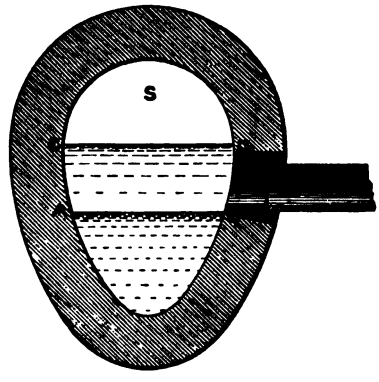
Ventilation by rain-water pipes.

Rain-water pipes have been very extensively adopted for the ventilation of sewers and drains. In Mr. Henry Austen's Report to the Commissioners of Sewers in 1849, he strongly recommended the use of these pipes in preference to shafts or furnaces; but experience has shown

that in those districts in which the system has been adopted it presents many disadvantages. Under certain conditions rain-water pipes are rendered totally inefficient as ventilators. For example, when ventilation is most needed it cannot be carried out by the rain-water pipes, for these pipes are invariably connected with the house drains, and the house drains are connected with the sewers; and if it is to be assumed that the rain-water pipe is to serve for the ventilation of the public sewers as well as the house drain, in time of heavy rainfall, when the sewers are gorged with sewage, and when the rain-water pipes are doing duty in their legitimate capacity, or are carrying away the rainfall, this system becomes totally inefficient for the purpose of ventilation, as the illustration, Fig. 61, will show. First, as regards the public sewers; because every junction made with a public sewer is made at such a point that if there is a small quantity of sewage flowing through the sewer the house drain may have a free outlet, as shown by the line A B, and at such times the rain-water pipes may serve as ventilators for a portion of the sewer. But the moment the sewers begin to fill in time of rain, and naturally to expel the gases which are present, the outlet of the house drain is effectually sealed with water, which may be of considerable depth, as shown by the water-line C D; consequently the whole of the gases which have accumulated in the upper section of the sewer S, and above the entrance of the house drain, become compressed, and soon acquire

Rain-water pipes used as ventilators.

Fig 61.



sufficient power to force a passage for themselves, and in such a direction as least anticipated. The sealing of house drains in times of storm shows the necessity of carrying out a system of public sewer ventilation totally independent of the ventilation to be provided for house drains. Moreover, as has been already mentioned, the rain-water pipes, during the time of rainfall, are doing duty in their legitimate capacity; consequently, at such times they naturally form inefficient ventilators, even for the purpose of house drainage. There are also other objections to the use of rain-water pipes, terminating under the eaves of a house or near windows, as the gases which may be discharged at certain periods will certainly find their way into our habitations. Rain-water pipes, terminating under the eaves of a house, are dangerous, as there is usually a space between the eaves and the roof, communicating with the interior of the building; so the sewer gas may permeate the building, and its evil effects will sooner or later be discovered. At Croydon it was found that the more rigorously the system of ventilation by rain-water pipes was pursued, the more unhealthy the district became; and it was not until special means were used, at the recommendation of the author, for the ventilation of house drains and the establishment of an efficient system of ventilation for the public sewers, that the death-rate of this town was at all reduced, as will be seen from the following facts. Early in 1860 "Bye-laws" were made which compelled the ventilation of the sewers by means of rain-water pipes. Previous to this, the ventilation had been chiefly effected by a small number of special ventilating pipes, which had been erected at various points along the course of the sewers, principally at their heads. After the passing of the bye-laws, for the first year or two they were not rigidly enforced, but, so soon as enforced, the rate of mortality in the district materially increased. For example, in 1860, the year in which this mode of ventilation of

Necessity of public sewer ventilation.

Objection to rain-water pipes.

Example of Croydon.

Mortality at Croydon.

the sewers was adopted, the rate of mortality was 16·63; in 1861, 18·00; 1862, 18·48; 1863, 20·4; 1864, 20·9; 1865, 21·26; 1866, 20·04; 1867, 16·6. This increase in the death-rate to the year 1866, and its diminution after that time, when the public ventilation of the sewers was carried out, tends to show how unsatisfactory were the results of the rain-water pipe system of sewer ventilation. If further testimony is needed on this point, it is supplied by the evidence of

Dr. Carpenter's evidence.

Dr. Carpenter, of Croydon, and published by him in a pamphlet, entitled 'Hints on House Drainage.' He says, "On inquiry I found that all the earlier fatal cases," [alluding to fatal cases of typhoid fever] "dated the commencement of illness from two distinct periods. Now those periods were preceded by a very heavy rainfall; on one occasion nearly 1½ inch of rain fell in the preceding 24 hours, and on the other, nearly 1 inch. On each occasion the temperature was high, and there was an entire absence of ozone in the atmosphere. I do not mean to assert that each case actually commenced immediately after the rainfall, but in upwards of twenty fatal cases, into the history of which I examined, the commencement curiously ran up to two distinct dates, and of many slighter cases the patients stated that they had not felt well from about the same periods. To what cause could those isolated cases of fever be attributed? how had the rainfall acted? and why should it act injuriously upon a perfectly well-drained town? Unfortunately for myself, an experiment was performed before my eyes which enabled me distinctly to point to cause and effect. My own house is connected with one of the main sewers, and has for many years been protected by a ventilating pipe, which, ascending from the soil pipe of the closet, was made to terminate for convenience near a cistern of large size, outside the top of the house. On the night of Oct. 17th, I was aroused by a loud noise proceeding from the closet; it continued at intervals throughout the next day. Unable at first

Typhoid fever and rain-water pipe ventilation.

to account for it, I eventually found that it was caused by the ventilating pipe doing duty as waste pipe to the overflowing cistern. There was no room for exit of foul air from the sewer, which therefore was forced through the trap of the water-closet, with, at times, the force of steam through the safety-valve of a steam-engine. The nuisance continued for nearly three days, before the weather would allow the plumber to rectify a mistake which had been committed in the previous summer; the mistake of making the ventilating pipe do duty for a waste pipe. The escaped air did not smell offensively, a faint odour alone being recognized; it was, therefore, thoughtlessly tolerated. The excessive rainfall also prevented much ventilation of the house by open windows. Two or three days afterwards one of the occupants of a room, the farthest in the house from the closet, fell ill with symptoms of typhoid fever, and in a few days the other person sleeping in that room also showed signs of the disease. No other person in the house suffered from it. In the room occupied by these two persons the foul air from the closet, as proved by experiment, naturally ascended."

Effect of ventilating pipes surcharged with water.

The ventilation of sewers by means of shafts communicating with the crown of the sewer, and terminating about the centre of the roadway, has been carried out in London, and many other places. In the opinion of the author this system of ventilating public sewers, when ventilators are provided in sufficient number, and furnished with materials for absorbing and destroying the escaping gases, is decidedly the best system that can be adopted. The objections raised against the use of simple openings into the sewer are that deleterious gases escape from them, and are left to take their own course comparatively uncontrolled. In combating this objection it should be borne in mind that gases escaping in the centres of roads become considerably diluted before they can arrive at the footpath or houses. The amount of dilution, supposing the gas to be uni-

Ventilation of sewers by shafts.

Dilution of sewer gas.

formly distributed through the atmosphere, would be proportional to the cube of the distance from the point of discharge, and dilution means in this matter something more than the dilution of effect. These open ventilating shafts act, at certain periods, both as up-cast and down-cast shafts, and the fact should not be lost sight of that they can be made as efficient when viewed in the light of ventilating shafts as the lofty shafts which have been before referred to, and at considerably less expense. The efficiency of a shaft is proportionate to the square root of its height; consequently, short shafts of larger area may be made quite as effective as smaller shafts of greater altitude. For example, take the case of a simple shaft terminating in the centre of a roadway, the sewer being 9 feet deep. Now such shaft, theoretically, if made three times the area of a shaft 81 feet high, would be quite as efficient; while in practice, the low shaft would be the more efficient, as there would be less friction. Moreover, less pressure will be exercised throughout a system of sewerage where ventilation takes place through low instead of high shafts. It may be here noted that any appliance, such as a chimney shaft or other special ventilating shaft, which is intended continuously to withdraw currents of air from the sewers, apart from its insufficiency as a ventilator, is bad in principle, for the fluctuation in the flow through sewers causing the dilation and condensation of the air brings into play forces far exceeding the power created by the ordinary draught of any chimney or shaft, even when aided by the heat of a furnace, so that despite the influence of these shafts when air is being naturally expelled from the sewers, all openings would discharge it, and when drawn in (if other openings were not provided) a current would be created down the chimney or shaft into the sewers. What, therefore, would come of such propositions as those of Mr. Spence* and others, who advise us

Shafts in roads efficient ventilators.

Principle of continuously drawing off sewer gas bad.

* *Vide* page 227.

that the drains and chimneys of our houses ought to be combined in one system, if at any moment we should be liable to an influx of sewer air and smoke into our houses? But apart from this grave objection, even if the combination could be made successful so far as our houses are concerned, the atmosphere of the sewers would be such that it would not be expedient to send men into them when they required repair, alteration, or the removal of obstructions. All shafts or chimneys of every description when used for the ventilation of sewers must be looked upon as having but little or no power in themselves to produce ventilation, but must be considered as a simple extension of the sewer for facilitating the discharge of noxious matter at some convenient point where it will be harmless.

Atmosphere of sewer such that men could not enter.

One of the most important things to be considered in connection with the ventilation of sewers is the disposal of the sewer gas in an innoxious manner. It should be observed, in reference to this matter, that the mere evidence of smell, or its absence, is no indication, or otherwise, of danger. Smelling gases may be harmless, while those matters which are most pernicious are usually devoid of odour. It has been already pointed out that the great safeguard against the evil effect of sewer gas is dilution; only allow the gas to combine with sufficient pure air and it is harmless, even if conveying the germs of disease. Evidence on this point is very conclusively shown by reference to our fever hospitals, which, in bygone days, when over-crowded and ill-ventilated, the death-rate among patients and attendants was awful to contemplate; but since these institutions have been provided with perfect ventilation, disease seldom spreads—in fact, if an attendant contracts disease, it is looked upon as sure evidence that the ventilation is defective, or in other words, that dilution of the fever poison is insufficient.

Disposal of sewer gas.

Evidence of effect of dilution.

The absorption of sewer gas by different substances has been proposed at various times, and is now very

Absorption of sewer gas by charcoal.

successfully carried out in practice. It is well known to chemists that all porous substances have, more or less, the power of condensing gases within their pores. Wood charcoal, as an absorber of sewer gas, is decidedly the most efficient and the cheapest agent that has hitherto been used for the purpose of absorbing or destroying the noxious property of sewer gas. Professor Muspratt's evidence. Professor Muspratt says that "the absorbing powers of charcoal are so great, that some have doubted whether it is really a disinfectant. This opinion has probably arisen from imperfect views of its *modus operandi*, since it not only imbibes and destroys all offensive emanations, and oxidizes many of the products of decomposition, but there is scarcely a reasonable ground of doubt remaining that it does really possess the property of a true disinfectant, acting by destroying those lethal compounds upon which infection depends." A piece of charcoal placed in a volume of sewer gas will absorb that gas. Charcoal attracts impurities of sewer air. It is not necessary for the gas to be mechanically brought into contact with the material, but just as the loadstone attracts iron, so charcoal attracts the noxious ingredients of sewer air. Professor Voelcker on powers of charcoal. Dr. Voelcker says of charcoal, "It possesses the power, not only of absorbing certain smelling gases—sulphuretted hydrogen and ammonia, but also of destroying the gases thus absorbed; for, otherwise, its purifying action would soon be greatly impaired. It is very porous, and its pores are filled with condensed oxygen, to the extent of eight times its bulk. We have therefore in charcoal, oxygen gas (which supports combustion or lights fires) in a condensed and more active condition than in the common air which we breathe. Hence it is that organic matter in contact with charcoal is so rapidly destroyed. The beauty of charcoal is that the destruction takes place imperceptibly, and that its power of burning organic matter is continually renewed by the surrounding atmosphere, so that it is a constant

carrier of atmospheric oxygen in a condensed state in its pores. The oxygen that acts on organic matter and burns it up is speedily replaced, and the process goes on continually. Hence it is that a comparatively small quantity of wood or peat charcoal is capable of destroying a very large quantity of organic matter."

The absorption of gas by different varieties of charcoal is given in Table No. 42.

Dr. Stenhouse on charcoal.

TABLE No. 42.—COMPILED BY DR. STENHOUSE, showing the QUANTITY of GAS in CENTIMETRES ABSORBED by HALF A GRAMME of CHARCOAL.

| Kind of Charcoal. | Ammonia. | Hydrochloric Acid. | Sulphuretted Hydrogen. | Carbonic Acid. | Oxygen. | Sulphurous Acid. |
|---|---|---|---|---|---|---|
| Wood .. .. | 98·5 | 45·0 | 30·0 | 14·0 | 0·8 | 32·5 |
| Peat .. .. | 96·0 | 60·0 | 28·5 | 10·0 | 0·6 | 27·5 |
| Animal .. | 43·5 | .. | 9·0 | 5·0 | 0·5 | 17·5 |

Professor Liebig.

Professor Liebig says, in his letters on chemistry, that "one cubic inch of beechwood charcoal contains pores equal in area to 100 superficial feet." As to the efficiency of charcoal for ventilators, Dr. Stenhouse says, "The efficiency of the charcoal appears never to diminish, if it is kept dry, and its pores are not choked up by dust." "The only precautions to be observed are, that while the filters shall be sheltered from rain and moisture, free access shall be given to the air." He also says, with regard to the construction of filters, "I should prefer using two or more thin filters, placed at short distances, say 2 inches from each other; these thin filters disinfect the air quite as efficiently as a single thick one." Dr. Letheby recommends charcoal air-filters as being the cheapest and best, as well as the most effective, plan for dealing with noxious exhalations from sewers. He says that charcoal has the power of "absorbing and oxidizing the miasmata of organic

Dr. Stenhouse on charcoal air filters.

Dr. Letheby recommends charcoal.

decomposition, when with atmospheric air they are passed over it." The charcoal used in the ventilators of the city sewers has been examined, and in the joint Report of Mr. Hayward and Dr. Letheby, on the use of the charcoal ventilators, it is stated, "Charcoal from the ventilators has been submitted to chemical examination after having been in action for nine to twenty months, and when treated with water it yields abundance of alkaline nitrate, showing that some of the organic miasmata have undergone complete oxidation. But besides these compounds, others are present, namely, peculiar alkaline salts, which indicate the fixation not only of ammonia, but also of other volatile nitrogenous bodies which are peculiar to organic decomposition. The nature of these compounds has yet to be determined. for all that can be said of them is, that they have a remarkably bad odour, compounded of urine, sewage, bad meat, ammonia, and stale tobacco; attempts have been made to isolate them, but without success. This however is not surprising when we consider that chemists have hitherto failed to separate and identify the miasmata of organic corruption." In the same Report it is further stated as to the power of charcoal, that "let them however be what they may, either physically suspended organic molecules, or complex volatile alkalies; and be the morbific agent either the one or the other, there is in charcoal a perfect means of arresting and oxidizing all the noxious compounds contained in these gases. This is demonstrated not merely by their absence in the sewer air which has passed over charcoal, but also by the presence of the alkalies, and the changed molecules in the charcoal itself." From what has been stated, it is clear that charcoal kept dry is practically a most efficient material for purifying sewer air, as it is not only a disinfectant, but it destroys or burns up the noxious gases. Some doubts may arise as to its use in connection with sewer ventilators, on

Report of Mr. Hayward and Dr. Letheby.

Matters arrested by charcoal proved by experiment.

Charcoal a most efficient agent.

account of the escaping vapours being highly charged with moisture; therefore on this point it is well that we should be assured that the moisture taken up from sewer air aids rather than impairs the efficiency of charcoal. In a paper on "The Absorption of Mixed Vapours by Charcoal," read before the Chemical Society on the 20th January, 1870, J. Hunter, Esq., M.A., gives the results of experiments with charcoal and moist vapours. These experiments show that if charcoal is introduced into a mixed vapour, the vapour "which is nearest to its point of condensation is first absorbed, and this in its condensed state in the pores of the charcoal aids the absorption of the other vapour. According to this view a succession of condensations is going on. The theory is strikingly illustrated in experiments with a mixture of water vapour and ammonia gas (obtained by heating an aqueous solution of ammonia of specific gravity 0·88), when the mixture is much more largely absorbed than either the gas or vapour separately." "The mean of a set of experiments made at 100° and a mean pressure 706·2mm. was 316·6 volumes of the mixture absorbed by one volume of charcoal." These experiments confirm our faith in charcoal as an absorbant of sewer gas, for they prove that the vapour of water, when near the point of condensation, as is the case with sewer air, instead of being prejudicial, greatly assists the absorbing power of the charcoal.

Effect of vapour of water on charcoal.

Other materials have been proposed to be used in connection with the abstraction and destruction of sewer gas; such, for example, as carbide of iron, a material which has been extensively used in the filtration and purification of water, and of which Mr. Spencer (its inventor) says, it is an extremely useful and durable material for the purpose of absorbing and destroying foul gases, and for the purification of air generally, and it was recommended by him to a Committee of the Houses of Parliament as the best means of removing

Carbide of iron.

the unpleasant odours from the air supplied to those Houses.

Lime. Lime has been used and repeatedly recommended as an agent for neutralizing or purifying the gases escaping from sewers. It has been proposed for this purpose on account of its having proved efficient in purifying ordinary carburetted hydrogen as used for the purpose of illumination. It is difficult of application to sewers, and will not prove so successful as charcoal.

Chlorine gas. Chlorine gas has also been proposed as a means of destroying the noxious property of the gases which escape at the ventilators provided for the sewers. Various modes have been suggested for liberating this gas; as, for example, by the use of common salt and nitric acid, or by placing materials rich in chlorine, such as chloride of lime, in trays, from which the chlorine would slowly evaporate into the surrounding air. Sulphurous acid has been proposed in connection with the deodorization or oxidation of sewer air, and experiments have been made with it by the Metropolitan Board of Works. The results of these experiments, so far as they are known, are given in a Report of Mr. J. W. Bazalgette, C.B., from which the following quotations are taken:—"At the suggestion of Mr. Cook, the member for the Poplar district, I have been for some time past engaged in trying experiments upon the deodorization of the foul effluvium from the sewers by means of sulphurous acid. The experiments were carried out in Northumberland Street, at the junction of the Euston Road with the Tottenham Court Road. Near the bottom of and within the shaft, at a point a little above the crown of the sewer, porous earthenware pipes were placed horizontally on the four sides, so as to form a continuous tube 7 ft. 6 in. long and 2 in. in the clear diameter. From thence an inch leaden pipe was continued upwards for a height of about 5 ft. 6 in., at which point it was con-

Sulphurous acid gas.

Mr. Bazalgette's Report.

Experiments on deodorization of sewer air with sulphurous acid gas.

nected with a glazed stoneware jar capable of holding about one gallon. The tube was then filled with sulphurous acid, and the pressure maintained therein by always keeping a supply of liquid in the jar. By this means the acid was kept constantly exuding through the pores of the pipe and brought into contact with the sewer effluvium as it ascended in the shaft. The wet evaporating surface presented to the current of foul air by the outer surface of the pipes was about 224 square inches."

"The mean results of many experiments, made under an average hydraulic pressure of 5 ft. 10 in., showed a consumption of less than 2 lbs. of acid of a specific gravity of 1·040 in 24 hours." "So far as the observations have gone, this agent, whilst in action, appears to have neutralized the foul smells." "Owing to leakages in the few pipes that were made for the purpose of the trial, there has been no opportunity for a continuance of the experiment in its original form, but upright porous pipes have been placed in this shaft, and in two other air shafts in Camden Road, of which complaints had recently been made, and these are now in working order."

Messrs. McDougall's apparatus.

"The Messrs. McDougall, the manufacturing chemists, have introduced a modification of the application of sulphurous acid, as first suggested by Mr. Cook, and which has been tried in an air shaft in Robert Street, Hampstead Road. The apparatus consists of a stoneware jar containing sulphuric acid, which is made to drop slowly upon a shallow tray containing a solid base consisting, I believe, chiefly of sulphite of lime, which results in the liberation of sulphurous acid gas, to the action of which the ascending gases from the sewer are exposed. Difficulties, however, have presented themselves in the working of this arrangement, as the proper, or uniform, intermixture of the two agents has not yet been effected for any lengthened period." From a further Report as to the experiments

Difficulties of applying the system.

in Tottenham Court Road, read on the 21st January, 1871, the following is taken:—"In the ventilating shaft in Tottenham Court Road, in place of the rectangular pipes laid horizontally at the bottom of the shaft (but which had become fractured), a length of about 5 ft. 6 in. of 2-in. porous pipes was placed vertically in the shaft, and connected with the reservoir near the surface of the roadway which had been used in the original experiment. This was kept supplied with acid, and the result of twenty-seven days' continuous working gave a consumption of about 53 pints of acid, or rather less than a quart per day." "At Robert Street the process has been varied by the introduction of a strip of flannel, which is placed in the shaft under the stoneware receiver that had been used in the former experiment with the solid base at this place, and by means of a stoneware tap the acid is regulated to drop upon the flannel, previously moistened with water. The result of thirty-eight days' working upon this system showed a consumption of about 65 pints of acid, or rather less than $1\frac{3}{4}$ pint per day, and in this case also the reports are to the effect that there is no apparent escape of effluvium from the shaft."

Action of sulphurous acid.

With regard to the action of sulphurous acid gas, in the words of Dr. Angus Smith, "it first deodorizes, but it gives off its oxygen easily, and acts as an oxidizer. It also acts as an acid, and dissolves animal matter. Its action is complex; it causes coughing, and it is in great quantities injurious to the lungs; how much in small quantities it is not known. It purifies the air from putrid matter, destroying that when in a state of vapour, as it destroys putrid and living bodies dissolved or in a liquid state, and it is therefore an excellent fumigator. How much it brings of other evils is an important question. It alters the air of towns entirely; every coal-burning town is compelled to breathe it." This gas, if present in excess, when escaping from a

ventilator, would be very disagreeable to many persons on account of its sulphurous smell, and when gas is used at those periods of the day when there are in-currents into the sewer the diffusion of a large quantity of sulphurous acid gas, would be attended with great inconvenience to the men who may be engaged within the sewers. There are great difficulties in applying the proper quantity of acid to manufacture gas for the destruction of gas. The gas, manufactured, itself becomes an impurity when present in excess, and if not present in sufficient quantity the sewer air would not have its poisonous properties destroyed. Neither sulphurous acid gas nor other gases have proved at present so efficient as charcoal, when properly applied, and moreover they are attended with considerably greater cost, and are by no means so easy of application.

Sulphurous acid may become an impurity.

Under certain circumstances the ventilation of sewers cannot be properly carried out unless the system of sewers has been constructed with special reference to their ventilation. It has been pointed out that sewers may act as chimneys, so that warm sewer air may be transferred by the sewers from the lower to the higher portions of the system. In order to obviate the evils arising from the transference and accumulation of gas in the higher portion of a sewered district, measures must be taken when, designing a system of sewers, so as to ensure the discharge and treatment of sewer gas as fast as it arises in any portion of the system. The mode usually adopted of preventing the transference of sewer gas from one portion of a district to another, is to take a small portion of the fall at every manhole or ventilator, forming, as it were, a step, which breaks the sewer into short lengths, so that the gas found in one length of sewer is allowed to escape at the upper portion of each separate section, instead of traversing the whole length of the sewers from the

Sewers need to be constructed with view to ventilation.

Mode adopted to prevent sewer gas travelling through the sewers of a district.

lowest to the highest points. Figs. 62 and 63 illustrate the principle involved in the system. Fig. 62 represents a branch sewer discharging into the main sewer at A. This branch sewer may be of indefinite length, and is

FIG. 62.

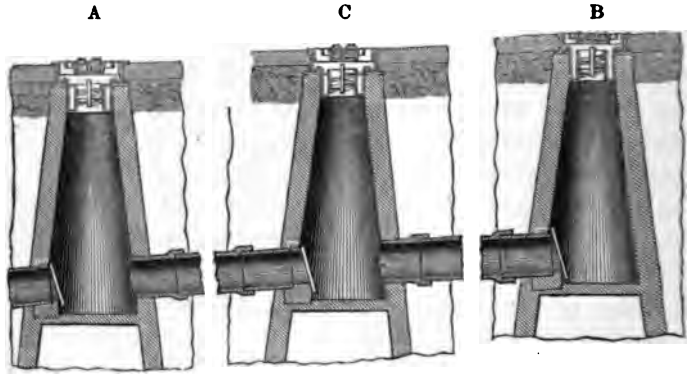
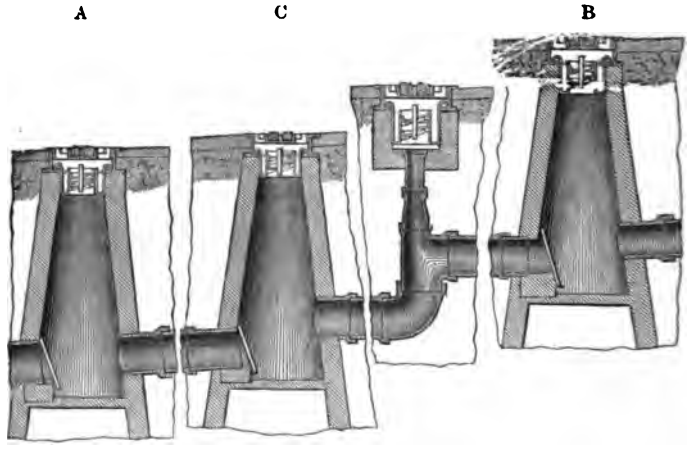



FIG. 63.




Sewers constructed in steps.

drawn with one uninterrupted fall, therefore the gases generated would naturally tend to ascend towards B, or will be driven upwards in that direction by any increase in the flow of the sewage causing the sewer air to be

compressed. If a ventilator is inserted at A, and another at B, there are certain times when air would enter at A and rush up the sewer to B with a velocity determinable by the altitude of B above A, and even supposing that there is an opening midway between the two points, or at C, the gases moving from A in the direction of B, having a given velocity, are moving in the same plane as the line of sewer, therefore they may leap across the opening at C and still continue to ascend the sewer and to accumulate in the neighbourhood of B. To remedy this defect and prevent the undue accumulation or transfer of gas, the sewers are broken up into a series of steps, as shown in Fig. 63. The gases, therefore, that are found at A or between A and C have a tendency to be discharged at C, because the sewer above C is not in the same plane as the sewer below C, and the gases, consequently, are directed out of the line of plane in which they were travelling, and are necessarily compelled to escape at C, and as every manhole becomes a shaft for drawing off the foul gas the comparatively short distance the manholes are asunder tends to make the whole system work very efficiently.

Flap valves used in connection with ventilation.

Other provisions are also sometimes necessary to be made; as, for example, lightly-balanced hanging valves, which fill the upper portion of the sewer, may be introduced with advantage to prevent a direct current of air from the lower to the upper districts. This arrangement is shown in Fig. 64. As a matter of precaution it is well, when sewers are constructed with steps, that the lower end of each section should be provided with a flap valve, or sometimes the combined effect of the draught caused by the shaft and the draught caused by the upper portion of the sewer may be such as to lead the gases onward up the sewer. In sewers of flat inclination the author has introduced chambers, in which gas may tend to accumulate, and discharge through a shaft ascending from the upper part of the chamber, as illustrated in Figs. 65, 66, and 67.

Ventilation of sewers of small gradient.

Fig. 65 represents the longitudinal section of the chamber of a brick sewer, Fig. 66 the transverse section of the same, and Fig. 67 represents the longitudinal section of the chamber formed in a pipe sewer. In this case the top and bottom of the chamber is formed of split earthenware pipes covered with concrete, and the sides are constructed of brickwork. These chambers in practice are found equivalent to the breaking up of the system of sewers as before described.

FIG. 64.

Forms of charcoal sewer ventilators.

It has been already stated that charcoal is a most valuable and efficient agent for absorbing sewer gas, and every system of ventilation of the public sewers should be fitted with an apparatus for containing it. Various forms of charcoal ventilators have from time to time

Fig. 65.

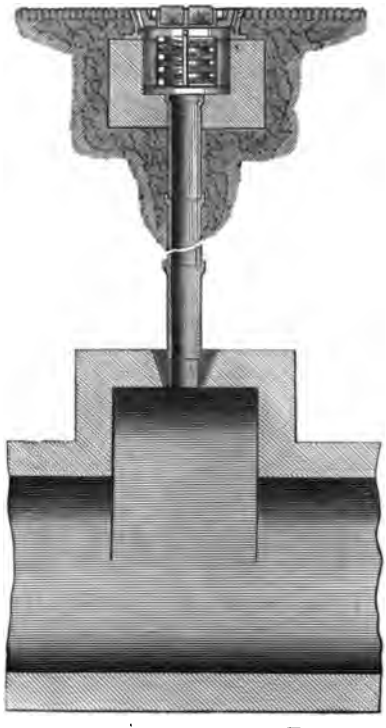


Fig. 66.

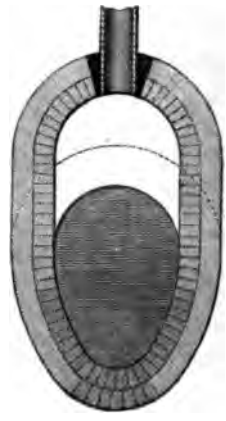
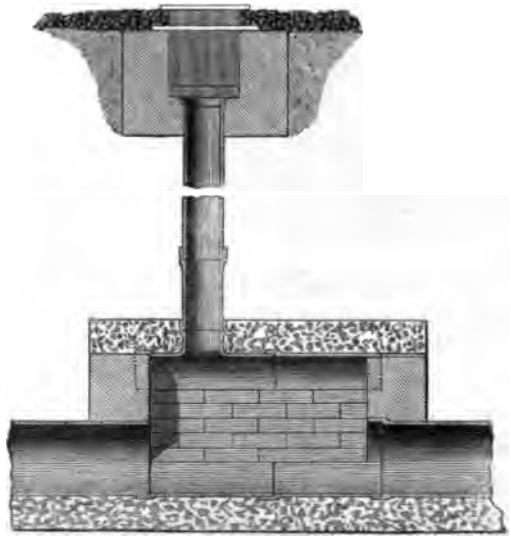


Fig. 67.



been used. It should, however, be borne in mind in using charcoal, that whenever it is used it should be so arranged as not to obstruct natural ventilation, and it should be kept perfectly dry, for it loses its power if it gets saturated with water. All those ventilators in which charcoal is placed in mass so as to completely fill the aperture provided for ventilation greatly interfere with the natural ventilation of the sewers, as anyone may ascertain for themselves if they will but make a single experiment with an ordinary bottle as used in experiments on ventilation. The experiment is illustrated in Fig. 68, which represents a wide-mouthed bottle having two tubes inserted in the cork; a light being placed within the bottle, a current of air is set up down one tube and up the other, as shown by the arrows. Now if a perforated tray containing a thin layer of charcoal is placed on the top of either of the tubes, ventilation is obstructed, and the lighted candle soon goes out. So it is with charcoal used in mass in sewer ventilators. Moreover, charcoal used in mass is liable to concrete together, and the pores and space between the pieces get stopped up with the dust blown and drawn into the open ventilators, so that in course of time the way through the charcoal is blocked, and ventilation completely stopped. Then the air of the sewers is corked up, and may acquire such a degree of tension as to be attended with inconvenience if

Experiment on natural ventilation.

Fig. 68.

Evil of employing charcoal in mass.

not with danger. In the construction of all sewer ventilators provision should be made for dealing with surface-water, rainfall, and the water produced by the condensation of moist vapour. So long as charcoal is brought in contact with the moist air of sewers it will retain its efficiency, but the moment it becomes completely saturated with water the condensed oxygen within its pores is driven out, and it ceases to absorb or destroy the noxious gases. Wherever ventilators are placed in the surface of streets, as all streets have, more or less, a fall longitudinally, in time of rain, the ventilator often becomes the receptacle for the water flowing from a very large area; as, for example, the water flowing downhill (especially in the case of a macadamized road) follows the ruts made by carriage-wheels, which if not allowed a free point of escape into the sewers would soon fill the receptacle provided for it, and then overflow and destroy the charcoal. Mr. Haywood and Dr. Letheby stated, in their Report to the City authorities, that "if the situation of the ventilators could be so arranged as to keep the charcoal dry, we are of opinion that it would not require renewal more frequently than once a year, but under existing circumstances many of them require to be changed not less than once a month." It has been proposed to prevent the water entering the ventilators by raising them above the general level of the road, but this plan is attended with inconvenience, and only partially meets the difficulty. Many attempts have been made to get rid of this water without injuring the charcoal, but most of such attempts have not been very successful, as the channel provided for the escape of the water also allows of the escape of the sewer air, or it is liable to get stopped up, and then the charcoal is destroyed by the overflow, just as if no channel had been provided for its escape. In the ventilator illustrated in Fig. 69 the charcoal is placed in trays which completely fill the shaft of the manhole. The introduction of trays of charcoal into manholes, as

Charcoal is destroyed by getting wet.

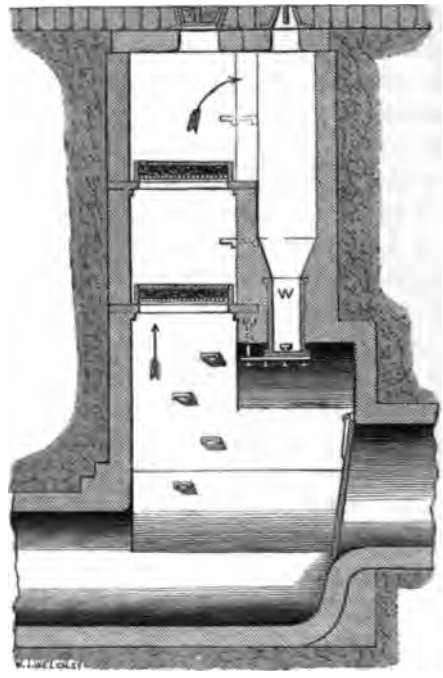
Duration of charcoal if kept dry.

Mode of preserving charcoal from wet.

Objections to forms of charcoal ventilators.

here illustrated, is objectionable; the charcoal being placed in mass interferes with the natural ventilation;

Fig. 69.




moreover, as these trays cannot be made to fit tightly round the sides of the manhole, sewer gases may pass without being brought into contact with the materials used for its destruction. This plan is also attended with much additional labour in renewing the material, or removing the trays from the manhole when men are required to enter the sewers. Fig. 70 shows a mode in which the charcoal is arranged vertically; it is still used in mass. The objections to this plan are, that wherever charcoal is placed in vertical trays, unless jammed in its position so tightly as to obstruct natural ventilation, in course of time it settles down, leaving an aperture over it by which the gases may escape without coming into contact with it. The use of a single ver-

Effect of charcoal in vertical trays.

tical tray will also allow gas to escape at the sides, as it is a matter of impossibility to render them air-tight. In the ventilator illustrated in Fig. 69 provision has been made for getting rid of the water by collecting it in a chamber, W, which is intended to be discharged at the bottom, when full, by hand labour. In Fig. 70 any water entering the receptacle W is intended to filter through the filtering medium at the bottom of the shaft to the sewer, but such a filter as this at first is very porous, admitting of the escape of gas, but in the course of time it becomes choked from the sludge entering by the open grating, so that when a large amount of rainfall is passed into the receptacle it does not flow away, but overflows and wets the charcoal. Fig. 71 illustrates an arrangement adopted by the Metropolitan Board of Works for experimental purposes. It consists of a single tray, containing charcoal placed over a vertical pipe leading directly from the crown of the sewer. The charcoal in this case is placed in mass, and no provision is made for getting rid of surface-water.

FIG. 70.

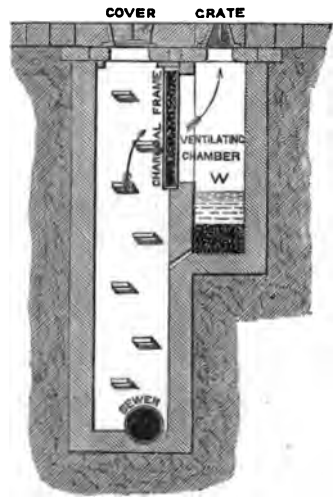
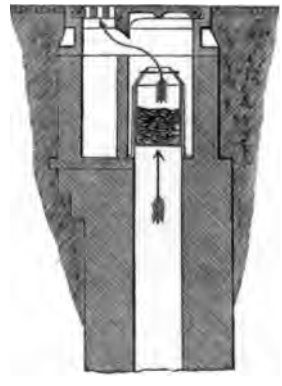



FIG. 71.



Metropolitan Board experimental ventilator.

Figs. 72 and 73 illustrate the arrangement adopted in some of the metropolitan districts for the ventilation of the sewers. Fig. 72 represents the system adopted

FIG. 72.

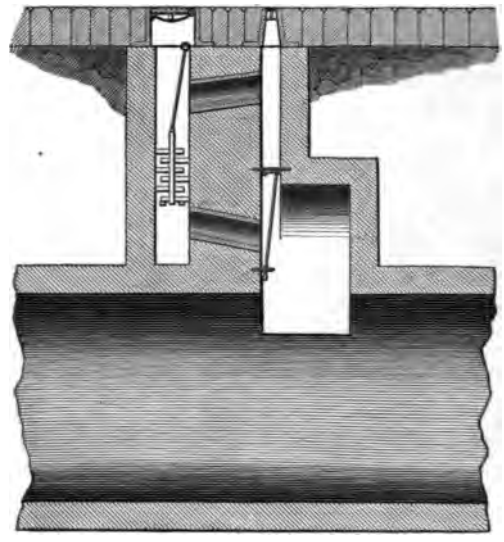
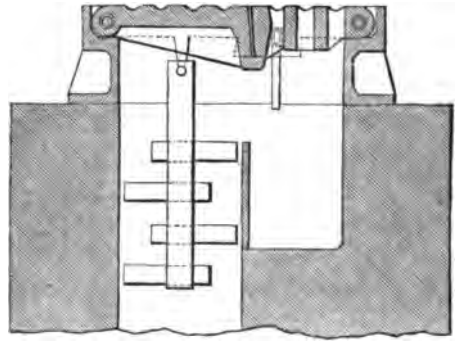


FIG. 73.



City sewers charcoal ventilators.

in the City sewers. The trays containing the charcoal do not fill the entire aperture of the ventilating shaft, but are laid zig-zag, so that there is an open space through the ventilator. This arrangement is decidedly superior to any system in which the char-

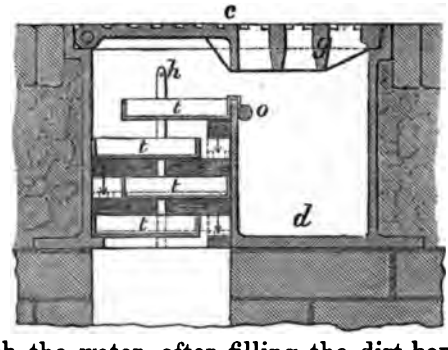
coal is laid in mass, as an opening is left communicating with the atmosphere on one side and with the sewer on the other. The charcoal is placed in trays, which are inserted in the shaft of the ventilator in such a position that the gas is brought in contact with it, while no pressure can be exercised in expelling the gases from the sewers. The faults of this system are that the ventilating trays cannot be made to fit tightly at the sides, therefore a small amount of gas can escape without oxidation by the sides of the trays. The dirt-box, moreover, is so small that in times of heavy rainfall it is quite inadequate, and speedily gets filled with water, which, overflowing, destroys the charcoal. The author, having used this description of ventilation very extensively, and finding that the charcoal so speedily got destroyed, introduced an improvement upon it, which is illustrated in Figs. 74, 75, and 76.* The improvement consists of an arrangement

Faults of this ventilator.

Latham's improved ventilator.

Description of improved ventilator.

FIG. 74.




by which the water, after filling the dirt-box, can be passed away to the sewers in such a manner as not to destroy the charcoal, and at the same time the channel for the escape of the water is so formed as to prevent the escape of the gas without its being brought in contact with the charcoal. Fig. 74 represents a section through the improved ventilator. *d* is the

* Mr. Alfred Williams, 64, Bankside, London, supplies these ventilators.

dirt-box, *t* the trays containing the charcoal, *h* the handle by which the trays are raised or lowered when required, *c* is the cover of the ventilator, *g* the grating

FIG. 75.

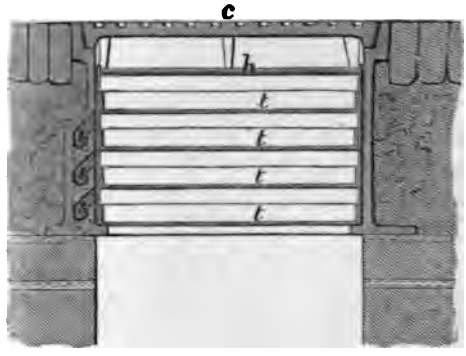
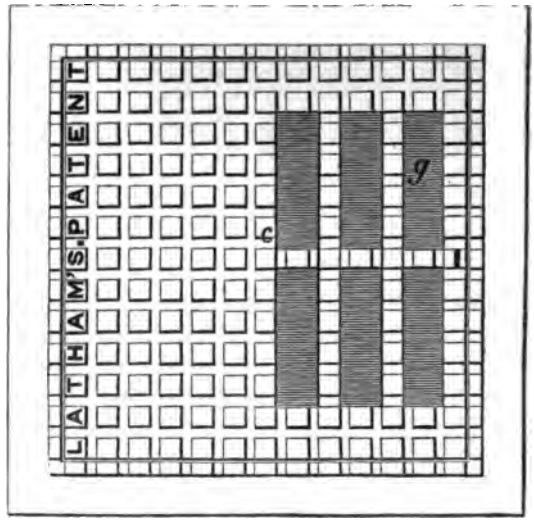



FIG. 76.




by which the air escapes, *o* is the mouth of the overflow in the dirt-box for receiving any surplus water, *s* the troughs for conveying the water away. They are arranged outside the ventilator, and are open to the underside of the trays of charcoal, as shown in the

longitudinal section Fig. 75. Any water entering by the opening *o* follows the direction of the arrows shown in Fig. 74, and so completely changes its direction that any gas entering the channel, in obedience to natural laws, must escape into the ventilator and be brought in contact with the charcoal, while the water flows away without touching the charcoal. Fig. 76 shows the plan of the ventilator on the top. Fig. 77 represents what is called Brooke's patent ventilator. The charcoal is placed in mass in a single tray, T, placed upon the top of the ventilating shaft in a manner analogous to that shown in Fig. 71. No provision is made for getting rid of any water which may enter the open ventilator, which is left to soak away, or overflow and destroy the charcoal. Messrs. Brooke have also another form of ventilator, which is used in combination with a street gully, and is illustrated in Fig. 78.

FIG. 77.

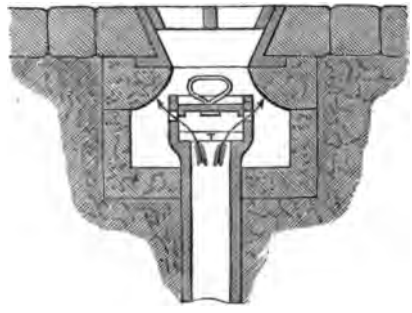
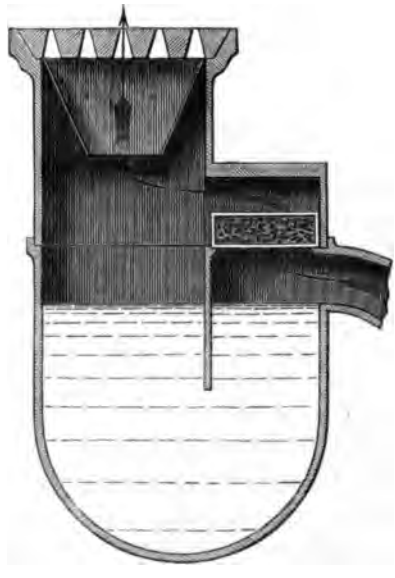


FIG. 78.

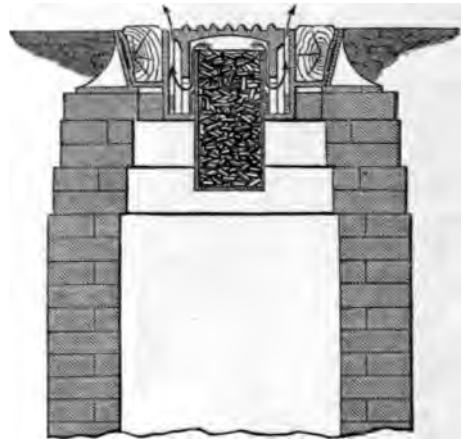
Brooke's ventilator.



Jacob's ventilator.

Mr. A. Jacob's patent charcoal sewer ventilator is represented in Fig. 79.

Fig. 79.



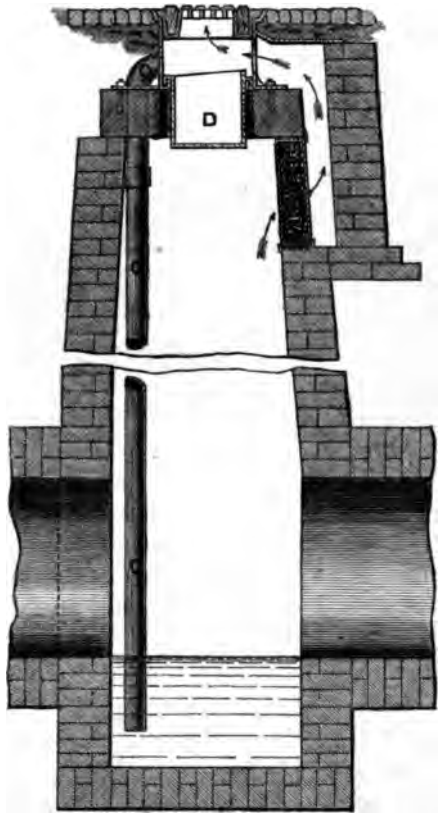
This ventilator is extremely compact in form, and is intended to be used in combination with a manhole, the charcoal arrangement forming part of the manhole cover. The charcoal is placed in a perforated cylinder in mass. The receptacle for the dust, dirt, and water is very small, so that the apertures provided for ventilation are liable to be speedily choked with dust or mud, and the means of disposing of the overflow water is defective. The overflow water in this ventilator is intended to be got rid of by small syphon pipes dipping into the dirt-box, but as these pipes will get speedily choked with mud, or may be frozen up in winter, they will soon become inoperative; and in the summer, should the dirt-box be emptied and the ventilator is not kept filled with water to seal the syphons, sewer gas will escape by them without coming in contact with the charcoal. In Fig. 80 is represented Harrison's patent charcoal ventilator. The arrangement of the charcoal in this ventilator is similar to that in Fig. 70, and the observations already made upon that form of ventilator equally apply to this form.* The improve-

Harrison's ventilator.

* *Vide* page 250.

ment in this ventilator consists of a movable dirt-box D, with an overflow pipe from the top carried

FIG. 80.



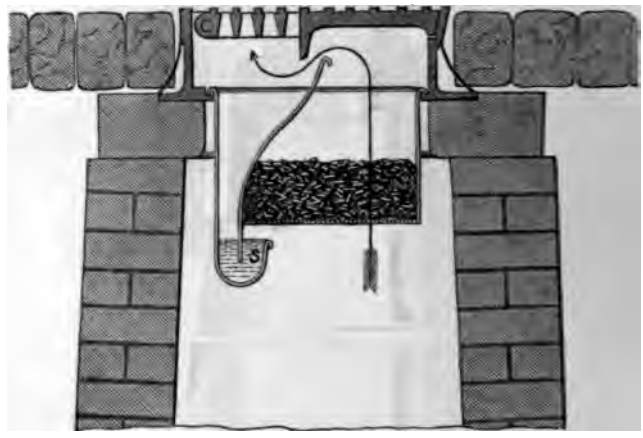

down to the bottom of the manhole, where it is made to dip into a pool of sewage, so that there is always an amount of sewage equal to the area of the descending pipe which is open to the street. In Fig. 81 is represented Hildred's patent charcoal sewer ventilator. The charcoal in this ventilator is placed in mass,* and consequently the objections to the use of charcoal in mass which have already been pointed out equally apply to this form of ventilator.

Hildred's ventilator.

* *Vide* page 248.

The overflow water from the streets is intended to be got rid of by means of the siphon trap S. It has

Fig. 81.




already been pointed out in considering the ventilator, Fig. 79, that siphons are not to be depended upon, and if the siphon arrangement of this ventilator did not block up with mud, or was not frozen up in winter, in summer it would become unsealed from the evaporation of the water in the trap, unless it was constantly renewed.

Latham's ventilator.

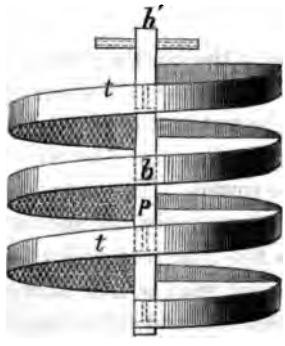
The imperfections in the various forms of charcoal sewer ventilators which have been brought into operation was the means of directing the author's attention to the subject, and in consequence early in the year 1869 he introduced an improved form of charcoal sewer ventilator which has been very generally adopted by the first sanitary engineers of the day, and which is free from the defects which have been pointed out in respect to other ventilators. The simplicity of construction of this ventilator and its economy in maintenance are points which will commend it to the reader's attention.*

* Mr. Alfred Williams, 64, Bankside, London, supplies these ventilators.

The action of this ventilator will be better understood by reference to Figs 82, 83, and 84.

FIG. 82.

FIG. 83.



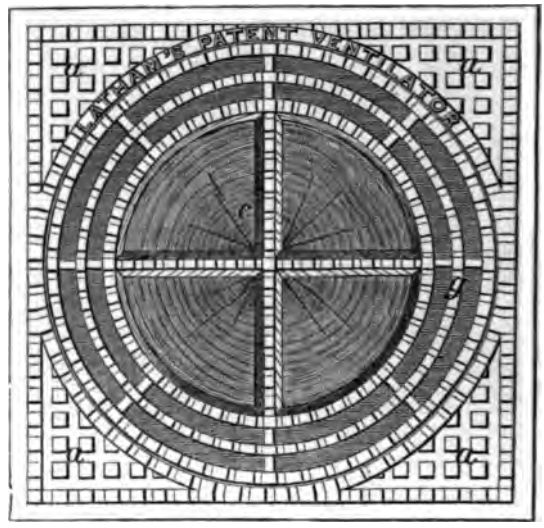

The larger sizes combine in themselves manhole-cover, lamphole, and ventilator, while the smaller sizes fulfil the two last offices. Each of the large ventilators consists of four parts :—

Description of ventilator.

1st. The frame *a*, for receiving the cover, and on the bottom of which hangs the dirt-box and charcoal venti-

lator. These frames may be made either circular or square, as shown in Fig. 84; the square form is best for paved streets or for square shafts, the circular for macadamized roads.

Fig. 84.




2nd. The cover *c*, the centre part of which is solid, so as to form an efficient cover for the charcoal and protect it from rain or the water used in street watering. *g* is the open grating in the cover by which air escapes or is drawn into the sewers. The openings of this grating are arranged concentrically, as shown in Fig. 84, and are formed with the aperture wider below than at the street level, so that mud is not likely to adhere, or if it does is soon removed and falls directly into the dirt-box immediately below the grating. Fig. 82 shows the cover, which in the illustration is shown filled in with wooden blocks (placed endways of the grain) for deadening the sound and giving an efficient foothold for horses. The covers, however, may be filled with any other suitable material, such as stone, concrete, or asphalte.

3rd. The dirt-box *d* hangs in a groove *x*, made in the

lower part of the frame *a*. The dirt-box is circular on plan, and the groove *x* is intended to be filled with fine sand. The weight of the dirt-box and ventilator pressing into the sand forms a gas-tight joint. *h h* are handles attached to the dirt-box for raising or lowering it. *s* represents an open spiral trough which forms part of the dirt-box, and which is used for conveying away the overflow water from the dirt-box to the sewer. *o* is a slot in the side of the dirt-box, communicating with the upper portion of the spiral trough, through which the water enters the trough.

4th. The spiral trays *t*, for containing the charcoal. The tray is shown in Fig. 83, and when the ventilator is in use the tray, after being filled with charcoal, is screwed into the ventilator over the spiral trough *s*, by means of the handle *h*. Each tray consists of a central shaft *p*, which is square, and out of every face project arms of T-iron, as shown by the dotted lines at *b*, Fig. 83. These arms are attached at the extremities by a strip of iron coiled spirally, and the bottom of the trays is filled in with network. The arms divide the whole tray into so many compartments for retaining the charcoal, which in consequence is kept in position, or otherwise it might have a tendency to slide down to the bottom of the tray. The trays are usually galvanized, to protect them from the action of the sewer air.

Advantages of Latham's ventilator.

To recapitulate the advantages of this ventilator: 1st. That should the charcoal concrete in the tray, or if its pores are stopped with dust, no impediment is offered to ventilation, as there exists a free communication between the sewer and the external atmosphere. 2nd. That the charcoal is completely protected from rain or water entering the ventilator or leaking through the joints of the cover, consequently it will retain its efficiency for a long period. 3rd. That the passage provided for the overflow water from the dirt-box is not dependent upon traps or any other uncertain device needing assistance to maintain it in perfect working

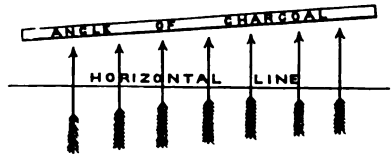
order. 4th. The escaping vapours are all brought in contact with the charcoal, it being impossible for any to escape by the sides of the tray or in any other way.

Action of Latham's ventilator.

The action of the ventilator may be explained as follows:—The spiral tray having been filled with charcoal broken the size of filbert nuts and screwed into the dirt-box, and the cover being placed in position, any mud or dust passing through the open grating will fall directly into the dirt-box. Any water entering at the grating would first fill the dirt-box, but when it had risen as high as the slot *o*, communicating with the upper portion of the spiral trough, it would overflow by this channel passing under the trays of charcoal to the sewer. The gases ascending from the sewer in obedience to well-known laws have always a constant tendency to ascend, and as the charcoal of the spiral tray is laid at an angle slightly diverging from the horizontal, the gases impinge upon the charcoal at every point of their ascent, as will be seen by reference to Fig. 85, which shows the angle at which the charcoal trays are placed; the arrows show the direction of the gases upon the trays of charcoal.

Arrangement of charcoal.

FIG. 85.




Any gases ascending by the spiral trough for conveying away the overflow water are brought in contact with the charcoal just the same as if they ascended by any other part of the apparatus. In this ventilator if the trays do not fit tightly at the side of the chamber no escape of gas will arise, as the trough for conveying away the overflow water projects into the ventilator, and any gas escaping by the side of the tray will be thrown against the projecting trough above, and so into the mass of charcoal. The circular form of the passage through the ventilator, moreover, causes the gases to move by a series of deflections, all of which

Trays not required to fit tightly.

Advantages of circular passage.

tend to bring it more intimately in contact with the charcoal, and the trays all being perforated there is nothing to interfere with the ready absorption of the gas by the charcoal. It has already been mentioned that the larger sizes of these ventilators combine a manhole-cover, lamphole, and ventilator, for by removing the cover and withdrawing the charcoal it forms a lamphole; by further withdrawing the dirt-box it becomes a manhole. The arrangement of having each part separately movable has its advantages, as the charcoal and dirt cannot get mixed. The dirt-box can be speedily and easily emptied by removing and capsizing it. The apparatus is easily fixed, and is economical in cost, as a much smaller amount of brickwork is required when it is used in connection with a manhole than is required in some other forms of sewer ventilator.

Advantages of movable parts.

The number of ventilators to be provided for the public sewers of a town ought to bear a constant ratio to the receiving and discharging capacity of the sewers. The experience of the author goes to show that the sum total of the area of the ventilating gratings should equal the discharging capacity of the sewers, the discharge from the ventilators should be computed as taking place under a pressure not exceeding one-tenth of an inch head of water. The ventilators should be placed closer together in the lower parts of a district, and the space between them may be somewhat increased in the upper part of the district. In no case in which houses are connected with the sewers should the distance between ventilators be more than 200 yards.

Number of ventilators to be provided.

Position of ventilators.

As to the duration of the charcoal in sewer ventilators, Dr. Letheby and Mr. Haywood considered that the charcoal would last for twelve months if kept perfectly dry.* In the author's experience, its duration depends upon its being kept dry, and also upon the work it has to perform. One ventilator cannot be expected to perform the work that should be distributed over a dozen, and a ventilator containing

Duration of charcoal.

* *Vide* page 249.

only a small amount of charcoal cannot remain efficient as long as a ventilator containing a much larger bulk of absorbing material, for the ultimate power of the absorption of the gas by the charcoal bears a constant ratio to the volume of the charcoal in use. It is true wisdom therefore to renew the charcoal at short intervals of a month, and revive it by reburning, rather than allow it to remain so long in the ventilators as to be practically useless. The amount of charcoal used in different kinds of ventilators varies very considerably; for example, the quantity used in a ventilator similar to those shown in Figs. 73 and 74, having four trays each 14 in. by 5¼ in., is 3¼ lbs. The quantity used in the author's spiral ventilator, Fig. 82, when combined with a 20-inch manhole-cover, is 6 lbs.

Amount of charcoal used.

Cost of charcoal ventilators at Croydon.

The cost of maintaining the efficiency of a system of charcoal ventilators may be arrived at from actual experience at Croydon, where there were, in the year ending the 25th March 1872, 562 public charcoal ventilators of various kinds at work, and which were maintained in a high state of efficiency by having the charcoal renewed every month. The cost of these ventilators, including labour, new charcoal, fuel used in reburning the old charcoal, &c., was 4*s.* 1½*d.* per ventilator per annum, or the whole system would have been covered by a rate of one-tenth of a penny in the pound, levied over the whole district. The charcoal is renewed at Croydon by being reburnt in a set of iron retorts, atmospheric air being excluded during the process. The escaping vapours are led away from the retorts by small pipes inserted in the end of each retort. After red heat has been maintained for a short time, the fires are allowed to die out and the whole apparatus to cool before the charcoal is withdrawn from the retorts.

Reburning the charcoal.

Ventilation of house drains.

The ventilation of house drains is of equal importance to that of the ventilation of sewers, for reasons that have been already pointed out and explained in Fig. 61,

page 230. Sewers cannot be ventilated efficiently through house drains, and on the other hand house drains cannot be ventilated by the public sewers. Every branch sewer and every branch drain needs its own separate and distinct ventilator. From the observations that have been already made with reference to the sealing of house drains in periods when the sewers are gorged with sewage, every house drain, unless ventilated, becomes a hermetically sealed chamber, and every drop of water entering a drain under such conditions compresses its atmosphere until it gains such a degree of tension as to force an exit, and the points of escape for sewer gas are usually the weakest traps, which, as a general rule, are always found in the interior of houses.

Ventilation required for every branch.

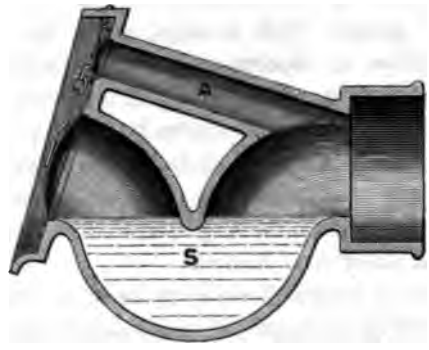
All kinds of propositions have been made for the ventilation of house drains by shafts and flues of various descriptions, including up-cast and down-cast shafts as used in mine ventilation, but as the effects of various kinds of shafts have already been considered in connection with the ventilation of sewers, it is unnecessary again to consider them. It may be observed, however, that as all such systems fail to ventilate sewers when applied to house drains, the failure is more marked and decisive as the forces at work within a house drain are the same as have already been pointed out as at work within a sewer, but are much more violent and irregular in their action. House drains are liable to constant and extreme changes of temperature, and to intermittent flow through them, conditions which materially affect ventilation, and at the same time render it indispensable if our houses are to be ensured against the escape of sewer gas into them. Notwithstanding the reasons that have been given, and which show that house drains cannot ventilate sewers, it has been seriously proposed to ventilate house drains into the sewers. Fig. 86 represents a form of trap intended to be introduced at the junction of a house drain

Propositions made for ventilation of house drains.

Proposal to ventilate drains into the sewers.

and sewer, whereby it is intended that the sewage should flow through the siphon-trap S, and the sewer gas should flow from the house drain through the pipe A into the sewer. There are conditions, as the inventors of this trap declare, when a current of air may

Fig. 86.




take place in the direction intended, but it should be observed that air would only take this direction when forced, as would be the case in a hermetically sealed drain, and a volume of water is passed into it which by increasing the pressure within the drain it would acquire sufficient force to escape by this passage into the sewer, but it would never naturally take that direction. On the other hand, the circumstances may often be such that it would be easier for the gas to force a trap within a house than to put in motion a descending column of air; moreover, what is to become of such a system of ventilation as this when the sewers are flooded, and when both the house drain and its air outlet are sealed with water, as illustrated in Fig. 61, page 230.

Objections to ventilation of drains into sewers.

In the experience of the author, the best way of ventilating house drains is the true Roman type of carrying up ventilating pipes at the heads of the drain and its branches. Care must be exercised as to the selection of a convenient point for the termination

Best mode of ventilating house drains.

of these ventilating pipes, especially in those cases where they are not fitted with a charcoal apparatus for absorbing or destroying the noxious properties of the sewer air. The point of exit should neither be near a window, ventilator, or the top of a chimney, as there are at certain periods currents of air at these points into the house, so that if the point of discharge is permitted to terminate near these openings, sewer gas may be drawn into our habitations. Great care should also be exercised in the selection of the material for the construction of ventilating pipes and for forming their joints, especially in cases where they have to pass through the interior of houses, for it must never be lost sight of that the superior temperature of the air of a house has always a natural tendency to favour the escape of sewer gas within rather than without the house. In Plate XI. is represented the section of a house with its arrangements for drainage, water supply, and ventilation of the drains. In this case it is assumed that the range of water-closets forms the head of the house drain, and the soil-pipe V is carried up and forms the ventilating pipe; which may terminate above the eaves of the house if there are no windows near, or it may be carried up the slope of the roof either inside or outside the building, and made to terminate a few inches above the ridge of the house. In the construction of new houses, the shafts for ventilating the drains may be formed within the walls of the house, in which case they must be made air-tight, and should be lined with glazed impervious tubes securely jointed. Where there are a number of branches to a drain, as for example, Fig. 87, A B C and D represent branches communicating with one common drain. Ventilation provided at the head of the drain, or for the pipe A, will not always give immunity to the other branches, and for safety, all these branches should be ventilated for the following reasons:—That induced currents will untrap all branch

Termination of ventilating pipes.

Selection of materials for ventilating pipes.

Plate XI.

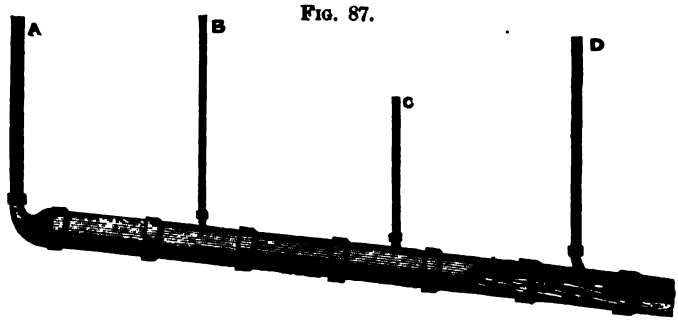
Shafts formed in walls.

Necessity of ventilating all branches of drains.

Influence of induced currents and waves of water.

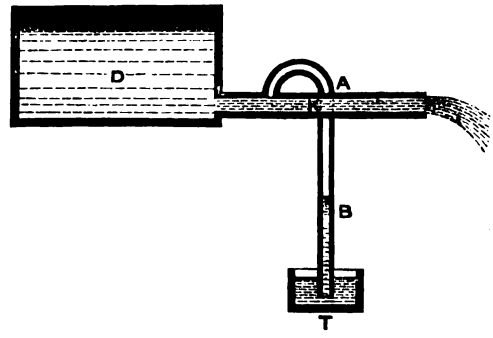
drains not provided with ventilation, or a wave or succession of waves of water, as shown at W, Fig. 87,

Fig. 87.




has the effect, as it moves forward down the drain, to compress the air in front of the wave and of creating a partial vacuum in the rear. The effect therefore is to drive the air up the branches in front of the wave and to draw the water out of the traps behind it. If the house drain at any time runs full bore, it is liable to drain in succession every trap on the branches A B C and D, unless each of these branches had been separately ventilated. This is due to the effect of an induced current. This action of moving water was discovered in the year 1797, by M. Venturi. Fig. 88 is an illustration taken from Ewbank's Hydraulics,

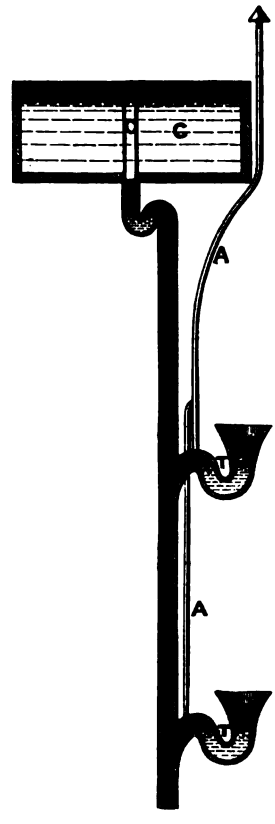
Fig. 88.




in which an account of the experiment is recorded as follows:—"The cylindrical tube K was connected

to a reservoir of water D, the surface being 32½ in. above its orifice. The pipe K was 18 lines in diameter and 57 long. A glass tube, A B, was connected to its upper surface at the distance of 8 lines from its junction with the reservoir. The other end of the glass tube descended into a vessel T, containing a coloured liquid. When water flowed through K, it dragged the air at the mouth of the glass tube with it, the remaining air dilated, and finally the whole was carried out with the effluent water, and the coloured liquid rose to the height of 24 in. in A B. The glass tube was then shortened to about 22 in., when the contents of T rose up and were discharged from K."

Fig. 89.




Experience as to effects of induced currents.

The author has seen an arrangement of drains in operation similar to that shown in Fig. 89. C represents a cistern on the top of the house; O is the overflow pipe, which is movable, so that at any time it can be removed to flush the drains or cleanse the cistern. The effect of discharging the contents of the cistern has been to effectually unseal the traps T when they have not been ventilated, and to induce a current of air to enter by these traps and pass along with the water, and so soon as the flow subsided it left the traps T open, and the drain in free communication with the house. Such an arrangement as here illustrated should never

Ventilation prevents injurious action of induced currents.

be used except when separate ventilating pipes are inserted at the top of the traps, as shown by the pipes A. If ventilation is introduced in this way, the effect of the induced current still remains, but air can enter the drain, and the traps will remain intact.

Charcoal applied to house-drain ventilators.

Charcoal may often be applied with advantage in connection with the ventilating pipes of sewers and drains; but in using it, it should be remembered that if not placed at the top of the ventilating pipe, it must be protected from the moisture which at some periods of the year will condense on the sides of the pipe, and trickle down and wet the charcoal so as to destroy its efficiency.

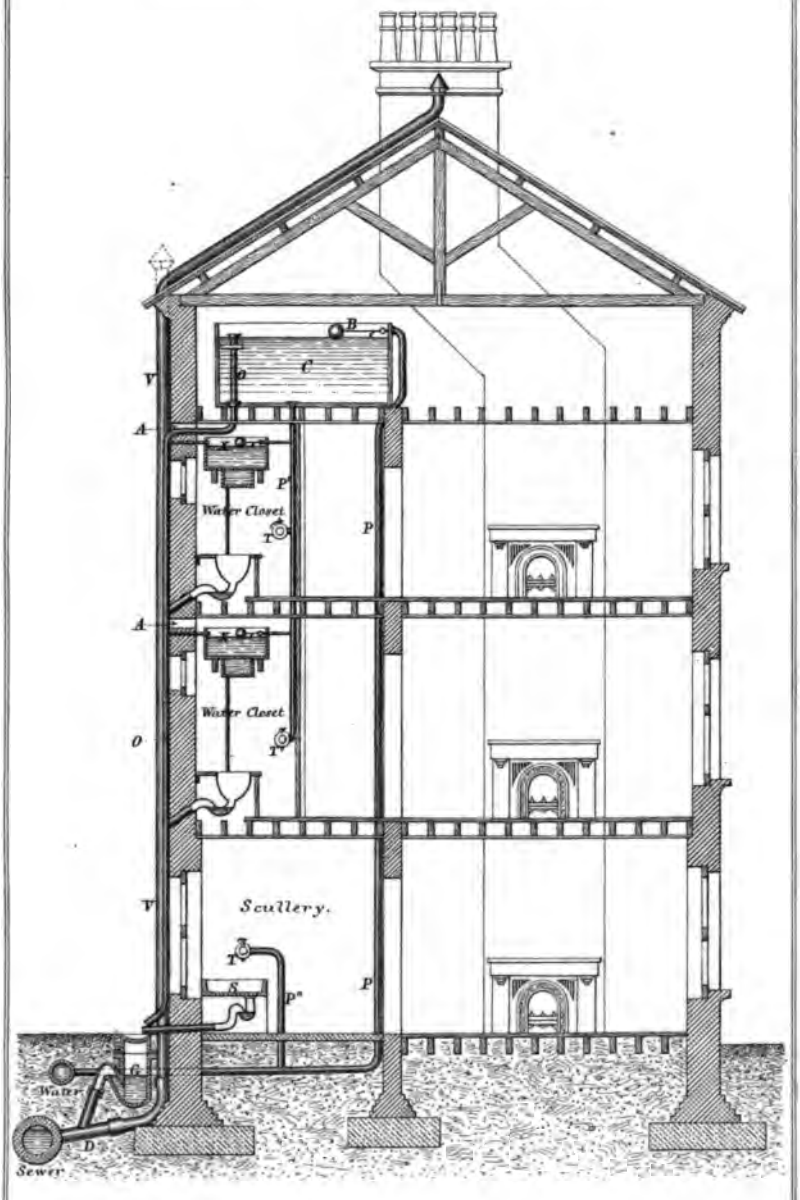
FIG. 90.

City sewers.

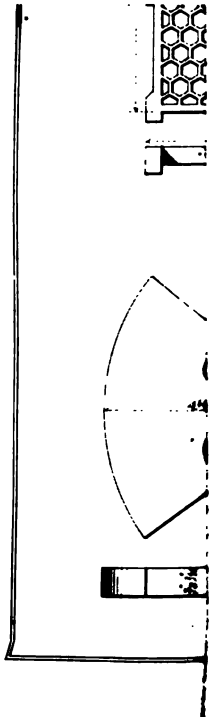
Ventilating pipes, as used in connection with the City sewers, have been fitted with an apparatus containing charcoal, which is placed on the summit of the pipe, as illustrated in Fig. 90.

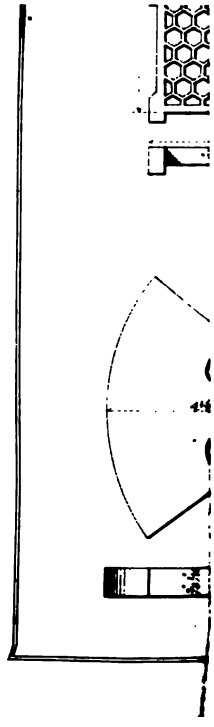
This arrangement is good if the trays fit the enclosing cylinder tightly, so as not to allow the gas to pass by the sides of the trays; but it is sometimes inconvenient to place an apparatus that requires attention in a position which is not always convenient of access, and on this account the author has applied a form of his spiral ventilator to ventilating pipes. For example, Fig. 91 represents a ventilator which may be placed at the head of a drain and below the ground level. The lid is kept tight by a sand-trap, from which a passage is provided to the spiral trough for conveying away to the sewer any water which may leak through the lid, and any condensed vapour descending the ventilating pipe also flows away by the spiral trough to

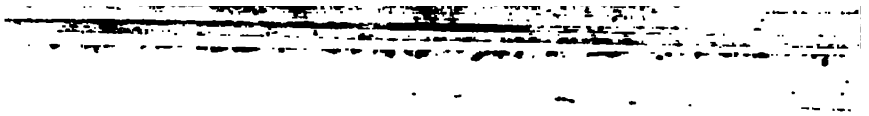
# HOUSE-DRAINAGE AND WATER-SUPPLY.




London: E. & F. N. Spon, 48, Charing Cross

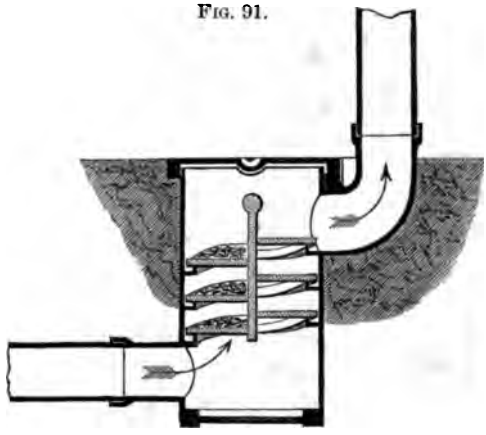






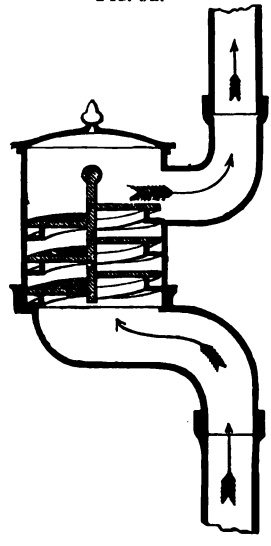
the sewer. This form of ventilator* should be used for the ventilation of sewers in courts, alleys, or confined places, for if from mischance the charcoal is neglected, Ventilation for confined places.

FIG. 91.



the sewer gas would ascend by the ventilating pipe, and be diffused in the atmosphere without causing any serious injury or annoyance. In Fig. 92 is represented another form of this ventilator, which may be fixed at any intermediate point between the ground line and the top of the ventilating pipe. If this form of apparatus is fixed near a window or other opening, it may be conveniently got at, and the charcoal renewed from time to time as required. Fig. 93 represents another form of the same description of spiral ventilator, which is applicable to the summit of a pipe.

FIG. 92.



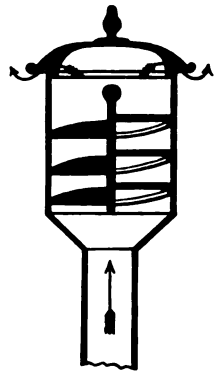
Charcoal ventilator applied above ground level.

Charcoal ventilation for top of pipe.

* Mr. Alfred Williams, 64, Bankside, London, supplies these ventilators.

The arrangement of this ventilator is such that the projecting worm in the interior of the apparatus prevents any gas passing by the side of the tray and so escaping contact with the charcoal.

FIG. 93.



Number and size of ventilating pipes for house drains.

The number and size of ventilators required for the efficient ventilation of a house drain ought to be equal to the discharging capacity of the house drain when working under a pressure not exceeding $\frac{1}{10}$th of an inch head of water. As a rule, the number and size of ventilating pipes now in use are too few and small for efficient ventilation. As an example, from Table No. 15, page 80, a 6-in. house drain, laid at an inclination of 1 in 50, would discharge 60·17 cub. ft. per minute. Now a 3-in. ventilating pipe 50 ft. long, calculated by the formula given at page 215, would only discharge 27·06 cub. ft. of air per minute, so that it would require at least two 3-in. ventilating pipes each 50 ft. long to effectually ventilate this drain.

Materials used for making ventilating pipes.

The materials used in the construction of ventilating pipes are copper, earthenware, iron, zinc, and lead. *Copper* is a good material, but expensive. *Earthenware* pipes may be used when built into a wall, but if applied outside they are cumbersome and ill-looking, and detract materially from the appearance of a house. Both cast and wrought iron are used with advantage. Enamelled wrought-iron pipes form one of the best of materials to be used for ventilating pipes. Cast iron is also a good material if care is taken in the jointing. Zinc is very extensively used for ventilating pipes, but it will not last long, as it is very subject to decay; it therefore should not be used in the interior of a house. *Lead* is a good material and is very durable. Care must be exercised in its use that it is not

brought in contact with lime, or it will soon become honeycombed and lead to the escape of gas. All ventilating pipes in the interior of a house should be so arranged as to be easily examined at any time. The pipes should also be tested under water pressure, to ascertain if they are air-tight, before being connected with the drains; and it will be well, in long lengths of ventilating pipes, to form expansion joints, for, if the pipe is fixed tight at any point, from its contraction and expansion under change of temperature, it is very liable to fail, and lead to the escape of gas. Angles and bends in ventilating pipes should be avoided as much as possible. Ventilating pipes need not detract from the architectural appearance of a house; indeed, on the contrary, they may be arranged in combination with vanes, bannerets, &c., so as to give architectural effect, therefore the unsightliness of a ventilating pipe should be no excuse for not providing this very necessary safeguard of life and health.

Testing the pipes.

Expansion joints.

Angles and bends.

Arrangement of ventilating pipes.

## MANHOLES AND LAMPHOLES.

No system of sewerage can be said to be complete unless amply provided with manholes and lampholes, in order to secure at all periods the proper supervision and control of the works. It has already been pointed out, at page 88, that sewers should be laid as nearly as possible in straight lines, with manholes at every point of lateral deviation, and manholes or lampholes at every vertical point of deviation. An illustration is given at page 90, Fig. 11, showing the way in which manholes and lampholes are used in case of a stoppage in the sewers. Previous to the introduction of manholes into the system of sewerage, great expense and inconvenience were often incurred in consequence

Manholes and lampholes required for supervision of works.

Position of manholes and lampholes.

Expense and inconvenience of breaking up streets.

of the stoppages arising in the sewers making it necessary to have recourse to breaking up the streets, probably in many places, before the stoppage could be discovered and cleared. Mr. Roe, when Surveyor of the Holborn district, gave it in evidence before the "Health of Towns Commissioners" that the cost of removing the solid deposit from sewers in the Holborn district, when provided with manholes, was 6*s.* 10*d.* per cube yard, as against 11*s.* per cube yard when the sewers were not provided with manholes. Moreover, it was stated that the Commissioners of Sewers of this district, in the year 1843, after paying the cost of constructing side entrances and flushing apparatus, had saved, at the end of the year, a considerable sum of money over and above what would have been their expenditure, in breaking up and restoring streets, and removing the deposit from the sewers, if the ordinary mode practised before the use of manholes had been adopted. The manholes of modern sewers are simply wells properly steined with brickwork, by which men can descend into the sewers, or, in the case of small sewers, to the sewer level. Lampholes are small shafts used for the purpose of suspending a lamp in order to throw a light into a particular part of a sewer, so as to enable men to inspect it from a manhole. Both manholes and lampholes should serve the double purpose of acting in their proper capacity, and also as ventilating shafts. Manholes are constructed either as perpendicular shafts, entering the sewer directly over its crown, or immediately by its side, or in the case of some towns, and in streets of great traffic, by means of side entrances placed either in the footpath, or at the side of the street, out of the way of the traffic. In Fig. 94 is represented the plan of a manhole, with side entrance, as used in the London sewers. Fig. 95 represents a section, showing the way in which the connection is made between the sewer and the side entrance. The object of a side entrance into a

Cost of removing silt from sewer with manholes.

Saving arising from use of manholes.

Description of manholes.

Description of lampholes.

Side entrances.

sewer is to enable the operations necessary to be carried on in connection with a system of sewers, such as

Object of side entrances.

FIG. 94.

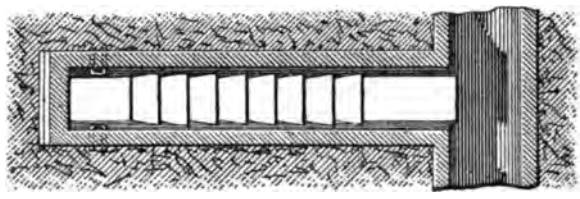
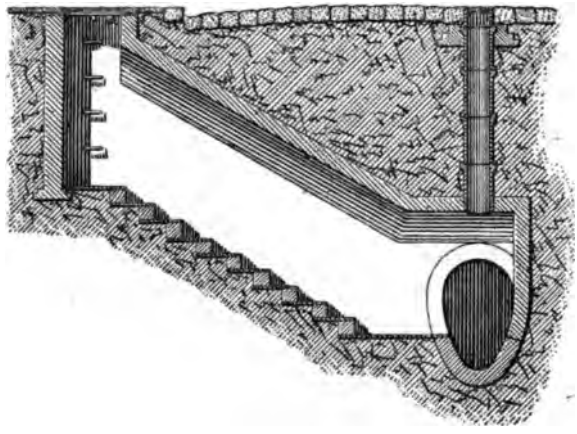


FIG. 95.



the raising or lowering of materials to or from the street level, without obstructing the street traffic, or being inconvenienced in the prosecution of the work by the traffic. No doubt the construction of side entrances into the old sewers of London was a great advantage, but the advantage is not so great in the case of a modern system of sewers so constructed as to be self-cleansing, and consequently not requiring the streets to be obstructed with the solid deposit raised from the sewers. Side entrances, except in rare cases are not imperative; they add materially to the cost of

Side entrances not required in self-cleansing sewers.

Ventilation of side entrances.

construction, and have some disadvantages, as they are apt to lead sewer gas to points near the houses. If it is necessary to introduce them they should be ventilated by pipes connected with the side entrance at the highest practical point immediately below the cover, and carried up to some convenient point.

Manholes preferable to side entrances.

In all ordinary cases a manhole, arranged near the centre of the street, is preferable to a side entrance, for then the manholes can be used as ventilating shafts, and moreover the removal of a simple manhole cover, having an opening not more than 2 feet in diameter, is, in practice, not found materially to interfere with the traffic of the streets.

Protection of open manholes.

It may be here observed that if it is necessary to remove a manhole cover, and to leave the site, the opening should be protected. This is ordinarily done by driving small wrought-iron standards into the street, and connecting them at their heads by a chain or rope.

Form of manholes.

Manholes are constructed both square and circular in plan. The manholes of a side entrance, or where the manhole is used as a flushing station, are usually square; but the cheapest, and one of the best forms of manhole is that of a circle in plan, made not less than 5 feet diameter at the bottom, and tapering upwards (or in the shape of the frustrum of a cone) to receive the manhole cover and charcoal ventilating apparatus, as shown in Fig. 54, page 185, and Fig. 64, page 246.

Comparison between manholes of various descriptions.

By comparing this form of manhole with those shown on pages 250 and 251, Figs. 69 and 70, it will be seen how much less brickwork it is necessary to use in the construction of a manhole, the top of which contains the ventilating apparatus, than is requisite when a separate chamber has to be provided for this purpose.

Thickness of brickwork for manholes.

When the manholes are circular, the sides are steined with bricks, radiating longitudinally: 9-inch brickwork is generally sufficient for most situations.

Manholes described in Plate IX

In Plate IX. is shown the general plan of the arrangement of the circular manholes, as designed by the author for the Sewerage Works of Dantzic. When

square shafts are used the thickness of brickwork is required to be considerably greater than with the circular shafts. The general arrangement of square shafts is shown in Plates V. and VI. These square shafts, especially in the case of side entrances, are covered with a manhole cover, usually consisting of a frame either of wrought or cast iron filled in with chequered plates, or sometimes with stone, slate, or asphalte, and generally provided with wrought-iron safety gratings. In fact, in some of the London districts, the sewers are partly ventilated by periodically opening the manhole covers and fixing the safety gratings. The details of these covers and safety gratings are given in Plate XII.

Square shafts, Plates V. & VI.

Side entrance covers.

Safety grating.

Plate XII.

In the construction of manholes, in some districts, especially in cases where sand is liable to find its way into the sewers, it is usual to construct the floor of the manhole at a lower level than the sewers running in or out of it, as shown in Fig. 80, page 257, so as to form a catch-pit for the deposit of sand. This is especially necessary where works of sewerage are in progress of construction in sandy districts: afterwards these receptacles may be filled up, and a channel formed across the floor of the manhole, so as to prevent the accumulation of any matter liable to decomposition. Manholes may also be used for storing up sewage for flushing purposes, as described at page 185, and illustrated in Fig. 54.

Catchpits in sewers, Fig. 80.

Manholes used for flushing sewers.

## GULLIES AND TRAPS.

A gully is an opening provided for receiving surface or waste water, slops, and the urine of men and animals. A trap is a barrier placed between the sewer on the one side, and the external or interior air of our houses

Gully.

Trap.

on the other side. Ewbank says, "The origin of traps is, we believe, unknown. The principle is precisely the same as that of water lute of the old chemist." Gullies and traps are closely related, for although we may have traps without gullies, no modern gully can be considered complete without a trap, and the trap and the gully are often so constructed as to be inseparable. Both gullies and traps are liable to a series of contingencies, arising from defects in construction or accidental derangement in working, rendering it extremely necessary to be cautious as to the mode of introducing trapped openings communicating with sewers or drains within our houses. All gullies and traps are now formed either on the water trap or valve trap principle, or by a combination of both these principles. All water traps usually partake of the character of an inverted siphon, and are liable to become untrapped from running full bore and acting as a siphon proper, in which case the induced current creates a vacuum below the trap; air follows the flowing water, and drives or sucks out sufficient water from the trap to leave the aperture unsealed. The remedy for this defect (which is constantly occurring in the case of small pipes) is to provide free ventilation below the trap, to make the trap of rather larger bore than the pipe communicating with it, and to cut off all direct communication with the drains of our houses in a manner hereafter considered under the head of House Drainage, page 319. Another, and not uncommon cause of the failure of a trap is, the entry of some substance which will act as a siphon, and drain every drop of water out of the trap, leaving it unsealed. For example, the traps of sinks are very apt to become untrapped in consequence of a thread or two of a dishcloth entering and hanging partly in the water of the trap and partly down the drain, when it acts as a siphon and drains the trap. The only remedy for this defect is the exercise of constant surveillance over all traps, and seeing that

Gullies and traps bear close relation.

Necessity for caution in use of traps.

Description of traps.

Causes of failure of siphon traps.

Remedy, ventilation.

Draining of siphon traps.

Remedy, frequent cleansing of traps.

they are kept properly clean, and, where possible, preventing all direct communication between our houses and the drains. Traps are also particularly liable to fail from the evaporation of the water which forms the seal against the escape of sewer gas. Valve traps are more defective than water traps, for it must not be forgotten that as traps are used with the sole intention of preventing the back passage of sewer gas from our drains or sewers, as water flows down, air, by the same law, flows up, so that, taking the case of the ordinary valve known as the shackle valve, Plate XIV., Fig. 22, when this is open, water is passing through the lower portion and sewer gas can easily pass back over the water through the upper portion of the valve. Other kinds, such as floating valves, have been used, but all valves are liable to leakage from the admission of some foreign substance into the valve seat which prevents its closing. Moreover, the oxidation of the valves, and the injury the valve faces often sustain, render them a very imperfect and unsafe mode of ensuring the trapping of any opening communicating with our sewers, and such valves can only be looked upon as a palliative against the movement of sewer air, and not as an effectual remedy to check its escape. The action of traps has proved so uncertain in excluding the foul air of sewers entering our houses, that persons have been found to advocate their entire abolition, and the substitution of free ventilation in their stead. Others have increased the number of traps in our house drains, in the hope of excluding more effectually sewer gas. Traps are useful for closing the openings between sewers and houses, or even between houses and the external air, for, if openings are left untrapped, and they simply communicate with the external air, at times disagreeable currents of air would be set up, which may be attended with inconvenience. On the other hand, if free ventilation is provided, unless openings communicating with drains are trapped, as air and gas always take the

Evaporation unseals traps.

Shackle valve.

Valves will leak.

Valve traps not to be depended upon.

Uncertain action of traps.

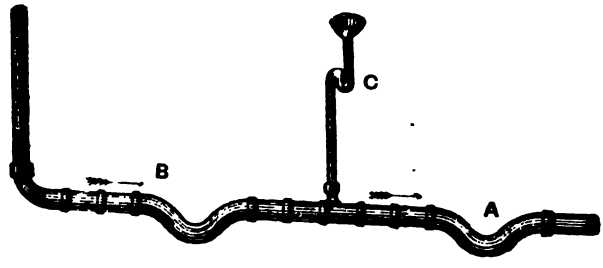
Use of traps.

Evil of multiplying traps.

course of least resistance, sewer gas may still escape into our houses. The multiplication of traps has also its dangers. For example, if two or more siphon traps are fixed in the same line of air-tight pipes, the lower siphon will effectually untrap the upper siphons, as for example Fig. 96. The siphons A and B are placed in

Description of Fig. 96.

FIG. 96.




the course of a drain with no free opening between them, water is passed into the drain above the siphon B; it will drive out the air in the pipe between A and B, which, as a general rule, would bubble up through the water of the trap at C. The air being excluded between A and B, all the siphons act in unison, and anything affecting the trap A or B will equally affect the trap C. For example, if the drain runs full bore, all the siphons would be drained, or in another case the lower siphon will effectually untrap the upper siphons; for if we suppose that water is running through the drain, and that it suddenly ceases to flow, the flow would gradually subside between B and A, causing a vacuum in this portion of the drain, and air will then enter through the siphons B and C, which will drive out the water in the trap, leaving it unsealed. The only remedy for this action of a siphon trap is to provide sufficient ventilation, so that while the action of the siphon remains, air may be supplied without having to pass through the traps. It cannot be too fully impressed upon all persons using traps, that no

Every trap protected by ventilation.

Fig: 21.

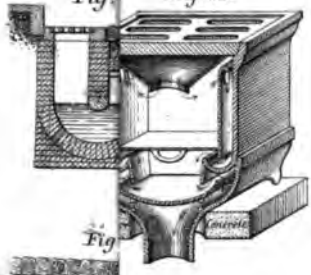


Fig: 22.

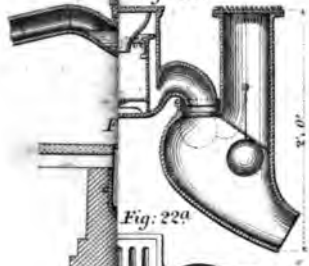


Fig: 22ª

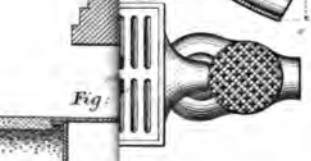


Fig: 24.

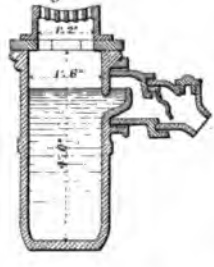


Fig: 25ª

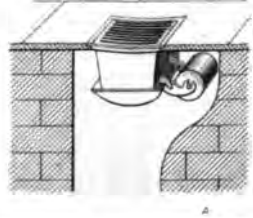


Fig: 26.

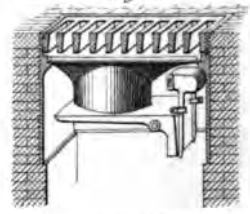


Fig: 26ª.

Fig: 27.

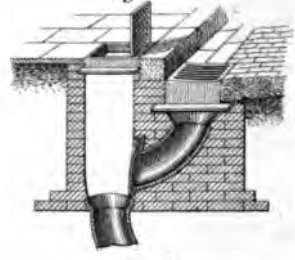


Fig: 28.

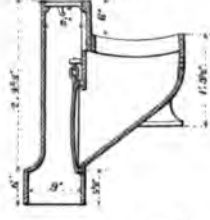
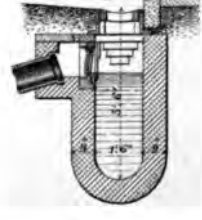


Fig: 29.



Kell. Bro.ª Lith.

Fig: 1.

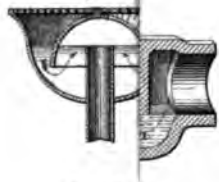


Fig: 2.

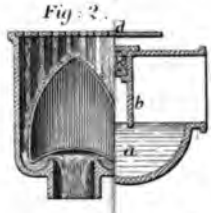



Fig: 3.

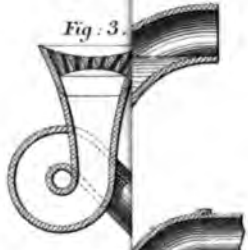


Fig: 4.

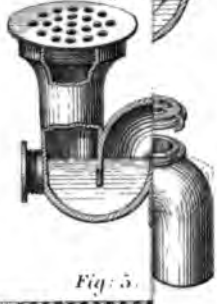


Fig: 5.

Fig: 18.

Fig: 19.

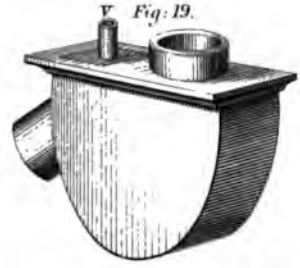


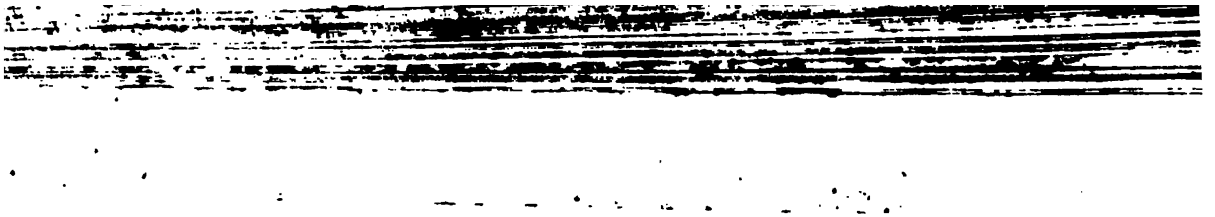
Fig: 20.

Fig: 20ª

Fig: 21.

Fig: 22.

Hall, Bro[d] Lith.



trap can be relied upon unless protected by a ventilator to relieve it from pressure.

Varieties of gullies in use.

The gullies in use at the present time are of two varieties; those which are intended to pass everything entering them to the sewers, and those intended to intercept all heavy matter, such as road detritus. In some districts where the sewers have ample fall and abundance of water for flushing, thus creating great velocity and transporting power, all such matters as enter gullies may be passed into the sewers, but in the generality of towns it is advisable to intercept the road detritus and other matters of this character, and to prevent their entrance into the sewers, as such matters are prone to concrete when they enter a sewer, and create stoppages which are both difficult and expensive to remove. All modern street gullies should therefore be constructed to intercept road detritus, and this can only be secured by making the catch-pit below the point of overflow into the sewers of considerable depth and size, and of such form at the bottom, that a rush of water, entering the gully in time of storm, is not liable to stir up the deposit and carry it away. In some sandy districts the author has found it convenient, in order to intercept the sand carried down a steep road in time of storm, to provide a special catch-pit outside the ordinary gully, in which the sand may subside. This arrangement is shown in Fig. 97.

Advisable to intercept road detritus.

Mode of intercepting detritus.

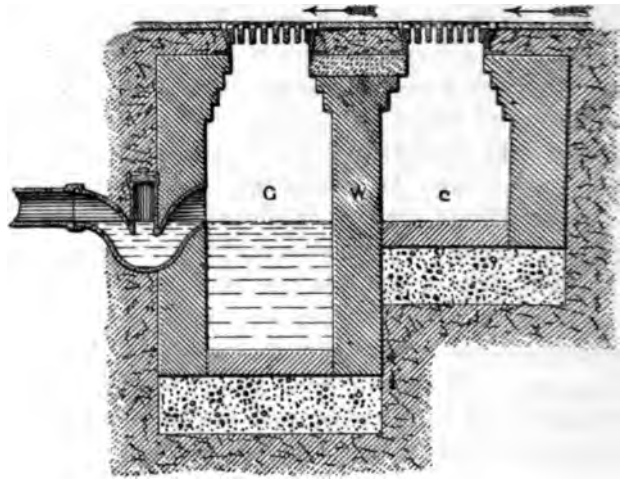
Special catch-pit.

Description of Fig. 97.

G is the gully-hole proper, and C the catch-pit for sand. When necessary a communication closed by a valve may be fixed in the wall W between the sand catch-pit C, and the gully-hole G. Water flowing down-hill in the direction of the arrows first flows over the open grating of the catch-pit before arriving at the gully grating; therefore, in time of storm, this catch-pit fills with water, and the heavy sand subsides in the water, the lighter substance flowing on to the gully. In a sandy district, in which such an arrangement as this is used, the walls of the catch-pit may with ad-

vantage be built in porous brickwork, so that, when a storm has subsided, the water may percolate into the

Fig. 97.




subsoil, leaving the sand in a fit state for removal.

Use of two gullies.

Some engineers introduce two gullies placed close together, in order to intercept more readily the solid matter brought down in time of storm.

Gullies should be impervious.

All trapped gullies should be constructed so as to be impervious to water, or otherwise a loss of water may take place from leakage, which in many varieties of gully will lead to their becoming untrapped. Some gullies are liable to become untrapped by reason of the

Effect of removal of deposit.

removal of the accumulation of deposit, which has the effect of lowering the water line. The gullies Figs. 14, 15, 16, and 21, Plate XIII., are not liable to fail from this cause, and on this account are preferable to other forms.

Effect of frost on gullies.

Gullies are liable to fail in time of frost, especially in very cold countries, as the gullies and traps get completely frozen up, and, when a sudden thaw takes place, they are found locked up with ice, so that the water cannot readily escape, and the streets in consequence

get flooded. The remedy for this is to remove the water in the gully as far as possible from the surface. In some of the northern towns of Germany the water line is removed five feet from the surface, and the gullies are constructed with special reference to the breaking up of the ice in the traps, should it accumulate. Fig. 11, Plate XIII., represents the section of a street gully which has been used very successfully at Carlsruhe, Germany. The gully is made in two portions, with a trap in the division wall. Should the trap get frozen, the stone S is removed from that portion into which the trap discharges, and a suitable tool may be inserted to break up the ice. It may here be stated that gullies communicating with the sewers proper of a town are not very liable to have their traps frozen, as the superior temperature of a sewer in winter effectually prevents the freezing of the traps; but in cases where a separate system is provided for surface drainage, the traps of gullies are very liable to freeze. In all cases gullies are liable to become untrapped from leakage or from evaporation; therefore, to ensure the integrity of the traps, they should have the water constantly renewed in dry weather. This is readily done in the summer months with the ordinary water-carts; at other times a special supply of water should be provided. All gullies should be regularly scavenged, not less frequently than once every six or ten days, as matters of a decomposable character are often passed into them, which decay, and give off offensive effluvium, if left too long in the gully. After every storm the deposit from a gully should invariably be removed from the catch-pit in order to prevent its being washed into the sewer. Gullies placed in situations more as a security against flooding, as in the floors of strong rooms and such like situations, are better sealed with oil, glycerine, or other liquid not so liable to evaporate as water. The gullies for stables and cow-houses should invariably be constructed with good-sized catch-pits, in order to prevent, as far as

Carlsruhe gully.

Temperature of sewer prevents freezing.

Water should be renewed in gullies.

Scavenging of gullies.

Fluid used to seal some gullies.

Gully gratings.

possible, the matters entering the sewers and choking them. Gullies are usually provided with grated coverings. Those for streets consist of bars, which should be arranged at right angles to the traffic, or otherwise narrow-wheeled vehicles are liable to get injured in the openings between the bars ofthe gratings. The gratings for yards and sinks are usually perforated, and are made either of iron, brass, or earthenware.

Selection of gullies.

Care should be taken when selecting a gully, that, if the grating is removed, the trap also cannot be removed, otherwise, from the inadvertence or carelessness of servants, the gullies or traps will be unsealed, as is invariably the case with the form of trap now in general use in most houses, and called the bell-trap, illustrated in Fig. 1, Plate XIV.

Bell traps.

In this trap the bell forming the seal is attached to the grating, and the removal of the grating, which enables servants more easily to pass matters into the drain, leaves the house in direct communication with the sewer. The locking of the gratings of sinks is an evil in an opposite direction.

Locking gratings.

Every grating should be made loose, so that the traps may be freed and cleaned of all matters contained in them, such as have already been mentioned, as likely to lead to the unsealing of the traps. The size of pipe used for connecting gullies in streets with the public sewers depends upon the area of surface a gully may drain, but in practice the pipe should not be less than six inches in diameter, and for yard drainage pipes of not less than four-inch diameter should be used to connect the gully with the drain.

Description of Plate XIII.

A great variety in the form of both gullies and traps has, from time to time, been produced. In Plate XIII. we have a number of illustrations of different forms of gullies.

Ixelles gully.

Fig. 1 is a representation of a section of a street gully as used at Ixelles, France. It forms a simple trap in itself, and is intended as far as possible to transmit all matter, both solid and liquid, to the sewer.

Gully with bottom trap.

Fig. 2 represents an English form of gully with a simple trap formed of earthenware at the bottom of the gully, and is constructed to transmit all matters to the sewers.

Cast-iron Continental gully.

Fig. 3 represents a Continental form of gully constructed entirely in cast iron, and intended to transmit all matters to the sewers.

Janniard gully.

Fig. 4 is the representation of a gully invented by M. Janniard, architect of the French Government. It is constructed in iron, and is intended to transmit all matters to the sewers.

Walker's gully.

Fig. 5 is a representation of Walker's trap. It consists of a pan hung with chains, so that the sides of the gully dip into the pan and form the trap. The pan can be detached on one side so as to enable any solid matter to be emptied out of it, which is then passed into the drain below.

Austin's gully.

Fig. 6 is a representation of Austin's gully trap. It is an improvement upon the common bell-trap, the bell not being attached to the cover, but loose, having a perforated bottom, and dropping down on the centre cone D. The top grating is hinged and can be raised, and so the trap can be easily cleaned out. B is the level of the surface, and C of the water; the arrows indicate the direction of the passage of the water to the drains.

Phillips' gully.

Fig. 7 is the representation of a street gully introduced by the Commissioners of Sewers for London, and is from the design of Mr. John Phillips, C.E. The catch-pit and trap are constructed entirely of earthenware.

London gully for narrow streets.

Fig. 8 is the representation of a London gully-hole, with the cesspit constructed under the footpath. The cesspool is placed in this position to facilitate its being cleansed, and this form was considered suitable for narrow streets of great traffic.

Gully for streets of great traffic.

Fig. 9 is the representation of a large gully with cesspit under the footpath. This form was considered suitable for streets of great traffic, where there was a large amount of road detritus to be intercepted.

Dantzic gully.

Fig. 10 is a representation of a street gully with earthenware trap. This gully is made of concrete and in one piece. Wrought-iron bands are introduced into the interior of the concrete to tie the whole together. It has been used in Dantzic, and the material is found to withstand the effects of the severe climate.

Carlsruhe gully.

Fig. 11 is a form of German gully used at Carlsruhe, which has before* been referred to in reference to the influence of frost on street gullies.

Lowe's gully.

Fig. 12 represents a section of Lowe's Patent Gully. This is a good form of gully for yards and such-like places.

Earthenware gully.

Fig. 13 is a representation of an earthenware gully suitable for small yards and courts, but the curved bottom, with the outlet near it with a large volume of water flowing through the gully, renders it liable to transmit detritus and other materials into the sewers.

Double-trapped London gully.

Fig. 14 is a representation of a double-trapped London street-gully, the smaller catch-pit B in this case is not so liable to the influence of evaporation as the exposed water area of the catch-pit A, and, moreover, the emptying of the larger cesspit still leaves the gully trapped.

Newton's gully.

Advantages of this gully.

Figs. 15 and 15*a* represent the plan and section of Mr. John Newton's gully. The advantages claimed for this gully are:—"1st. A perfect trap at all times, the ordinary siphons ceasing to act when the level of the water is reduced by the removal of deposited matters. 2nd. Very little evaporation in summer, and no liability to freezing in winter. 3rd. Ample space for the retention of the road detritus. 4th. In the event of any solid matter accumulating in the trap, it can easily be removed when the gully is emptied. Provision is also made for flushing the drains through an aperture fitted with an air-tight stopper in the upper part of the trap. 5th. Unusual facilities in the fixing, no brickwork, stone, or cement, being required. 6th. Economy in first cost and durability." In ordinary cases gullies of this

* *Vide* page 283.

kind 1 ft. 6 in. × 1 ft. × 2 ft. 9 in. are recommended, but when the gullies are less than 40 yards apart a smaller size may be introduced, or 1 ft. 2 in. × 1 ft. × 2 ft. 2 in. These gullies are made entirely of cast iron. Distance gullies are placed apart.

Fig. 16 represents a form of gully that has been used by the author for many years past. The trap is of the flat siphon variety, and is not affected by the lowering of the water line in the gully. Instead of being provided with a plain siphon of the variety shown in the drawing, it may be furnished with a siphon and junction for inspection, as shown in Plate XIV., Fig 16*a*. Gully designed by author.

Fig. 17 is a representation of the section of "Butt's" Gloucester gully, with loose dirt-box. "The grating *a* and the dip *b* are made separate for the convenience of casting and lifting off, and the lower part of the dip *b* drops into a sediment-box, which box rests on and is regulated by half-bricks *d d*. By these means a stench-trap is formed with the water surface reduced, so as to lessen the evaporation, a desideratum in times of drought. The sides are formed of brickwork. As the water and filth pass through grating *a* and down the dip *b*, they are finally lodged in the box *c*, which can be emptied by one man, by merely lifting out the box by the handles and emptying it into the scavenger's cart, thus avoiding the offensive and expensive mode of cleaning hitherto practised of pit traps; the water running over in the direction of the arrows, ultimately escapes through the drain pipe *e*." It should be observed that unless the drain *e* is trapped, the removal of the dirt-box leaves the drain untrapped. Butt's gully with loose dirt-box.

Fig. 18 is a representation of "Sharp's" Lancaster double-trapped gully, with movable dirt-box. This form of gully is very similar to that shown in Fig. 17, and unless provided with a trap below, as shown in this illustration, the removal of the dirt-box leaves the gully untrapped. Sharp's gully.

Fig. 19 is a representation of "Clark's" Carlisle Clark's double-trapped gully.

double-trapped gully, with movable dirt-box and bottom discharge. This form of gully would be untrapped by the removal of the dirt-box.

Clark's gully, with side discharge.

Fig. 20 is a representation of Clark's double-trapped Carlisle gully, with movable dirt-box and side discharge. This gully would remain trapped after removal of the dirt-box, provided there is sufficient volume of water retained in the bottom of the casing to compensate for the loss arising from the displacement of the water by the removal of the dirt-box.

Clark's treble-trapped gully.

Fig. 21 is a representation of Clark's treble-trapped gully, with movable dirt-box. The great advantage of this form of gully consists in the fact that it remains trapped when the dirt-box is removed. In all the forms of Clark's gully the dirt-box is provided with a perforated gallery round the top, so that they will retain floating substances, an advantage which the other forms of gully we have considered, with movable dirt-box, do not possess; consequently with them such matters are washed over the lip of the box into the drains.

Gully for low situation.

Figs. 22 and 22*a* are illustrations showing the section and plan of one of Clark's gullies combined with a Young's valve-chamber. "These chambers and valves are constructed for the purpose of preventing the back-flow of sewage from drains in low situations in times of flood. They consist of a chamber fitted to the outlet-pipe of a street, or court gully, in which is suspended an india-rubber ball, which on ordinary occasions hangs clear of any surface water entering the chamber from the gully, and in times of flood is floated into a gun-metal seat at the mouth of the chamber, thus preventing any back-flow from the drains reaching the surface. These ball-valves are self-acting, requiring no attention after once being fixed. The interior of the chamber is provided with guides to conduct the ball into its seat, and so made that the ball cannot possibly become fixed. A movable water-tight cover is also provided for the purpose of inspection if required." Another form of

this gully and valve-chamber is made specially adapted for smaller drains, and can be readily applied to a house drain, and is very suitable for the drainage of cellars and other places liable to be flooded from the sewers. Prevention of flooding of cellars.

Fig. 23 is an illustration of the section of a catch-pit and valves of an iron gully as used at Brighton. It combines both a dip and valve trap. Brighton gully.

Fig. 24 is an illustration of the section and valves of a very similar gully to the former. It is made of earthenware by Messrs. Henry Doulton and Co., and is intended to be used as a street gully. As valves cannot be implicitly depended upon as efficient traps, these forms of gullies should all be filled up with water after being freed from sediment, in order to bring into action the water-trap which is provided. Doulton's gully

Figs. 25 and 25A are representations of a totally different kind of gully from those which we have hitherto been considering. It is called a balance gully. The gully may be allowed to fill up with water or dirt until the load accumulated overcomes the resistance of the balance-weight attached, when the valve tilts and discharges the contents of the gully into the drains below. This form of gully, although in use in many towns, cannot be recommended, for after careful examination the valves are never found to be tight, materials get under them that prevent their closing; and, moreover, every time they discharge their contents, they allow sewer air to escape, as every discharge displaces at least an equal volume of the sewer air. Balance gully. Valves never remain tight. Discharge of the sewer air.

Figs. 26 and 26A are representations of "Thompson's" balance-trap. The advantage claimed for this particular form of balance-trap is that it cannot gape, as other balance-valve traps do, with a load only slightly exceeding the balance-weight, as, in addition to the balance-valve, a balance-latch is provided, and sufficient weight must accumulate to move both the latch and pan before the valve will open, when it opens suddenly, and quickly closes after discharging the contents of the Balance gully with balance catch.

gully. The pan is supposed to be kept air-tight by closing against a ring of vulcanized india-rubber. This form of trap has the same defects as have already been mentioned in considering the previous form of balance-valve.

Shackle valve.

Fig. 27 represents a gully trapped with a shackle-valve, with manhole for inspection provided in the footpath.

Shackle valve and hole for inspection.

Fig. 28 is an illustration of a shackle-valve gully and inspection hole made in one frame of cast iron.

Islington gully.

Fig. 29 is an illustration of a gully with catch-pit and shackle-valve trap. This form of gully is used by the Islington Vestry. The catch-pit is built in bricks and cement, and is 1 ft. 6 in. × 3 ft. × 5 ft. 6 in. Such a gully as here represented cannot be recommended, as, whenever it is brought into action by water opening the valve, sewer gas can always escape by the open space above the water-line. Moreover, it is liable to fail from other causes, which have already been considered when speaking of valve traps.*

Description of Plate XIV.

In Plate XIV. are represented numerous forms of traps which have been introduced at various times for sealing the inlets of drains and sewers, and preventing the escape of sewer gas.

Bell trap.

Fig. 1 is an illustration of the section of the ordinary bell trap. These traps consist of a bell attached to the grating and dipping into the water, retained in the chamber of the trap, and covering the discharge-pipe. The seal of these traps rarely exceeds one quarter of an inch in depth, and they cannot be depended upon, as servants will remove the grating and the trap with them, and so place the house in direct communication with the sewer. Moreover the small amount of seal provided in traps of this class is soon lost by evaporation, especially in the heated rooms in which they are often placed.

Clark's valve-trap.

Fig. 2 is an illustration of the self-acting valve trap

* *Vide* page 279.

of Mr. Clark, of Reading. It consists of a lead receiver 4½ in. diameter, with a brass grate on the top. The receiver holds about half an inch of water, into which the outer edge of the hollow-turned copper ball dips when its indented bottom rests on the top of the outlet-pipe, forming a valve trap. When water enters through the brass grating, the ball floats and allows it to escape, but so soon as the flow subsides, the ball resumes its position. This is a decided improvement on the ordinary bell trap, but is liable to be tampered with, and both the grating and valve may be readily removed, leaving the drain untrapped.

Trap for Surrey and Kent sewers.

Fig. 3 is a form of sink and siphon trap, introduced in the year 1848 for the Surrey and Kent sewers, and specially adopted for sinks of sculleries and areas.

Tye and Andrews' trap.

Fig. 4 is an illustration of Tye and Andrews' sink-trap. Its advantages consist in the greater depth of seal provided. The gratings are usually locked, which is no advantage, as servants should be instructed not to cast matters down the gullies which they are not intended to receive, and also to periodically clean out the trap in order to free it from those matters liable to unseal it. Ample space, therefore, should be provided in all traps, so that the hand may be freely inserted for the removal of any matter prejudicial to the action of the trap. In the plan of cutting off the sinks from drains, which is hereafter considered at page 319, when adopted, servants will soon find out that to pass any matter not intended to be received by a trap, is not to get rid of it, but that it will again be brought to light on the outside trap or gully.

Cutting off sinks from direct communication with drains.

Antill's trap.

Fig. 5 is a representation of Antill's trap with Stidders' lock grating. This forms a very efficient trap for a sink, as, like the previous trap it cannot be tampered with when the grating is removed.

Finch's soap trap.

Fig. 6 is a trap manufactured by Mr. Finch, of Holborn, suitable for a lavatory, constructed in order to catch soap. The plug at the bottom may be removed,

and the deposit of soap taken out. A is the pipe leading from the bottom of the basin, B is the overflow-pipe from the basin, and O the discharge-pipe.

Earthenware sink trap.

Fig. 7 is an illustration of an ordinary earthenware sink trap with square top.

Brookes' trap.

Fig. 8 is an illustration of a horizontal house trap by Messrs. Brookes', of Huddersfield.

Brookes' trap, down outlet.

Fig. 9 is an illustration of a house trap by Messrs. Brookes, of Huddersfield, but supplied with a down outlet.

Lowe's trap.

Fig. 10 is an ordinary house trap of Lowe's pattern.

Rain-water pipe trap.

Fig. 11 is the alteration of a trap for a rain-water pipe, as manufactured by Mr. Clark, of Carlisle. Traps in connection with rain-water pipes cannot be depended upon, unless the means are provided for constantly renewing the water in the trap, as in periods of long-continued dry weather the water will evaporate and the trap be rendered useless.*

Traps useless in dry weather.

Gully and trap.

Fig. 12 represents a combined gully and trap. This form of apparatus will be found extremely useful in a variety of places, when ordinary traps could not be depended upon. Such a trap as this placed upon a main line of a drain through which water is always flowing, would never become unsealed in dry weather, and therefore could be depended upon when other traps would fail for want of water to seal them.

Advantages of this trap.

Position of ventilation pipe.

Fig. 13 is an illustration of an ordinary trapped gully, showing the proper position of the ventilating pipe.

Mansergh's trap.

Figs. 14 and 14A are illustrations of the plan and section of Mansergh's trap. This trap is specially intended to prevent the ingress of sewer gas into houses by "waste and overflow pipes from cisterns, baths, lavatories, bath and lavatory safes, and sinks," and is always to be placed outside the house. In one piece of stoneware two water seals are formed, and between the two is an open communication to the air by means of the surface grating. If, therefore, the

Advantages of this trap.

* *Vide* page 325 as to mode of treating rain-water pipes.

pressure in the branch drain is sufficient to force the gas through the first or lower seal, it will escape into the air, and cannot possibly pass the second seal, and so enter the house. It has the advantage of receiving the waste water underground, out of sight; there is, consequently, never any foul water on the surface. The open grating admits of its serving as a yard gully.

Cottam's trap.

Figs. 15 and 15A are illustrations of Cottam's traps. In Fig. 15 the trap is provided with a ventilating pipe, and in Fig. 15A charcoal is applied in mass, through which sewer air which may pass the trap is allowed to escape. This form of trap is called by its inventor the "Intercepter Trap," and is intended to be fixed close to the outer wall of the building. "The receptacle for the water-lute is in two compartments *a a*, into each of which a diaphragm or plate *b* dips, and an intercepting chamber *c* is thus formed, by means of which the sewer gas forcing a passage is caught and carried off by a pipe *d* to any convenient place for its escape."

Flat syphon trap.

Figs. 16 and 16A are representations of an ordinary flat siphon trap. The latter illustration is provided with a junction for inspecting and cleaning the trap when required.

S trap.

Figs. 17 and 17A are representations of an S trap, so called from its being of the shape of the letter S. The latter form illustrated is fitted with an opening on the top of the trap, closed with an air-tight cap, made after the manner of the stopper of a pickle jar.

P trap.

Fig. 18 is an ordinary P siphon trap. This form of trap is largely used, and is well adapted to form the trap of a water-closet, and is much more readily flushed and kept clean than some other forms of siphon trap.

D trap with ventilation pipe.

Fig. 19 is the representation of a D trap, with ventilating pipe V. This form of trap is very generally adopted by plumbers, and is usually made in lead. It is also made in earthenware. It is a dip trap which forms a siphon, but it is not such a good form as the other traps hitherto considered.

Gulley trap.

Figs. 20 and 20A illustrate two forms of trap used in connection with gullies, but are not ordinarily so good as those represented in Figs. 16 and 16A, for reasons already given.

Shackle trap.

Fig. 22 is an illustration of a pipe fitted with a shackle valve. This pipe is supposed to be inserted into the outfall sewer, to prevent the entrance of foul air and vermin passing up the house drain. The defects of this form of trap have already been pointed out in considering the subject of valve traps. It may here, however, be observed that valves of this description may often be used with advantage in a line of sewer for the purpose of preventing the ascension of any large volume of sewer gas, and so may be made to assist ventilation.*

Traps of this description aid ventilation.

Block valve.

Fig. 23 is an illustration of a shackle valve attached to a block of earthenware, and usually called a block valve.

## TIDE VALVES.

Protection of outfall sewer.

When it is necessary to carry an outfall sewer into a tidal stream, or into the sea, and the point of outfall is below high-water mark, the outfall must be protected with a tidal valve so as to prevent the ingress of water into the sewers of the district. It is also necessary, in some cases, to protect the rain outlets or storm-water overflows of sewers in a similar manner. This was found necessary in the case of the sewerage works of Dantzic, for although sufficient engine power has been provided in this town to raise both sewage and ordinary storm-water, yet, as a matter of precaution, a number of storm-water overflows have been provided, so that, if the engine power necessary to raise the volume of water brought down by the sewers should prove insufficient, or the engines should get disabled,

Protection of rain-water outlets.

Dantzic an example.

* *Vide* page 245.

the sewers would simply overflow and discharge into the river Mottlau and the branch streams communicating with it. Now, as the Baltic Sea, into which this river discharges, is a tideless sea, it might be thought to be a simple matter to arrange the storm-water outlets so as not to require protection; but in order to ensure all the advantages of having a low outlet in time of storm, the level of these outlets was fixed at a lower point than the ordinary water-level of the river, for although the Baltic is a tideless sea, the water level of the river Mottlau has been known to vary 7 feet, between extreme high and low water, in a season, the cause of which is principally due to the action of strong prevailing winds. The most remarkable point in respect to the rise and fall of the water in this river, and the one which led to the fixing of these rain-water outlets below the level of ordinary water, is that the district is visited with the heaviest rainfalls, when the wind is in such a direction as to lower the mean height of the water in the river, and consequently, by fixing these outlets at a lower level than ordinary water-mark, the discharge of heavy storms will take place under circumstances that are most favourable to the sewers. It has already been mentioned that it is necessary to protect an outfall sewer from currents of air entering and passing up them in uncontrolled volumes, and so deranging all the means provided for ventilation and the destruction of the noxious gases.* If outfalls are of such size, and in such situations, that they cannot be made to discharge below the water-line, so as to seal their mouths, they must be provided with tidal valves. Tidal valves are ordinarily of two varieties:—Tankard valves, deriving their name from being similar in action to the lid of a tankard, and float valves. The tankard valves are constructed of wood, wrought, and cast iron. Wooden valves are very extensively used

Prevention of currents of air entering outfall.

Tidal valves: two descriptions.

Wooden valves.

* *Vide* pages 42 and 212.

in connection with drainage works in the Fen districts of this country, and, if made of good elm or oak, will last for a considerable period. Valves of this description made of wood are also formed like a lock-gate, or two doors meeting at an angle and closing against both bottom and cap sills. Wrought-iron tidal valves of cellular construction have been used with advantage for large outfall sewers. They are light, strong, and durable. Cast iron is the ordinary material used for tidal valves in works of sewerage. Float valves are usually made of copper, or india-rubber, or wood coated with india-rubber, but they are only applicable to sewers of small size. They consist simply of a float moving between guides, and when the water rises the float rises into the bell mouth of a pipe and closes the aperture. All tidal valves should be so balanced as to be capable of opening with the smallest amount of internal pressure, and to close with the least amount of external force. A properly constructed tide valve is entirely self-acting, and the sewers regulate their discharge so soon as the height of the water outside the valve is lower than that within the sewer. All the working parts of a tankard valve should be bushed with gun-metal to prevent the valves sticking. The doors of cast-iron tankard valves should be strengthened with ribs, suitably disposed, so as to give them lightness and strength. These valves may either have planed faces to keep them water-tight, or lead seatings fixed in the frame may be provided, or in some cases both the face and seat may be formed of gun-metal. The doors of these valves are hung with both single and double hinges. The double-hinged doors have a greater amount of play, and in most situations are the best. In Plate XV. is illustrated a number of different kinds of tide valves.

Made like lock-gate.

Wrought-iron valves.

Cast iron ordinarily used for sewers.

Float valves.

Tidal valves should be balanced.

Working parts should be gun-metal.

Hinges of doors.

Description of Plate XV.

Shackle valve.

Fig. 1 in this plate is an illustration of an ordinary shackle valve. This form is only applicable for sewers of small size.

Dantzic rain outlet valves.

Figs. 2 and 2A are illustrations of rain-water outlets as designed by the author for the Dantzic sewerage works. The rib R cast in the pipe attached to the valve is intended to prevent the water creeping along the sides of the pipe through the brickwork in which it is embedded. The door of the valve is provided with a lead face which closes against a V seating. The valve is provided with a ring O, to which a chain may be attached in order to open the valve and admit water to the sewers, if required, for flushing or any other purpose.

Tide valve with link hinge.

Figs. 3 and 3A illustrate an elevation and section of a cast-iron tide valve, hung with links, forming a double-jointed hinge.

Tide valve fitted to pipe.

Figs. 4 and 4A illustrate an elevation and section of a cast-iron tide valve fitted to a length of cast-iron pipe, and hung with double hinges.

Tide valve with single hinge.

Figs. 5 and 5A illustrate an elevation and section of a cast-iron tide valve fitted to a length of cast-iron pipe, and hung with single hinges.

Tide valve for oval sewer.

Figs. 6 and 6A illustrate the elevation and section of a cast-iron tide valve for an oval sewer, provided with double hinges.

Oblong tide valve.

Figs. 7 and 7A illustrate the elevation and section of an oblong cast-iron tide or storm-water outlet valve, hung with double hinges.

Tide valve in double flights.

Figs. 8 and 8A are illustrations of the elevation and section of a cast-iron tide valve opening in two flights. This form is adapted to the construction of large valves, but care must be exercised in their fitting and finishing, otherwise the hinge in the centre of the door will be liable to stick, and the valve to get out of order.

Mode of intercepting pure rainfall from sewers.

Fig. 9 is an illustration of the mode of intercepting large and pure rainfalls from sewers, and admitting the small and impure rainfalls. It is fully described at page 26.

## PENSTOCKS.

Use of penstocks.

Penstocks are sluices fixed in a sewer for the purpose of regulating or controlling the current, or to stop the flow and pen up the sewage when required for flushing or any other purpose.

Penstocks used as a safeguard.

The use of penstocks in some situations is absolutely necessary, as, for example, in the case of a tidal outfall; they should invariably be fixed as an adjunct to a tidal valve, so as to secure the closing of the sewer in the event of any accident happening to the tide valve which may prevent its closing and excluding the tidal waters. They are also used in cases in which it may be necessary to divert the sewage from one line of sewers into another line. Penstocks are made of wood and iron, or a combination of both. The penstocks usually adopted in sewers are made with cast-iron frames and doors. They can be made of any size or shape.

Mode of raising doors.

The doors are usually raised or lowered by a rack and worm-wheel motion, or by chains passing over drums. The rack and worm motion is decidedly the best, as it is found that doors raised by chains are liable to move by sudden jerks, which are prejudicial to the stability of the apparatus.

Faces of doors.

The doors are kept water-tight by having the face of the frame, and the face of the door planed or fitted with gun-metal, and the faces are brought into contact by means of wedges fixed on the back of the door and in the frame, so that, when the door is lowered, it wedges itself up tight against the face of the frame.

Mode of fixing.

In fixing penstocks, especially in cases where the doors are made of wood and are liable to spring, the hydraulic pressure should be so arranged as to press the door with its rack against the worm-wheel. The doors of all large sluice valves are usually provided with counter-weights to balance the door and to diminish the labour of raising them. They are also

Compound gearing.

often fitted with compound gearing for opening them, as, for example, Fig. 1, Plate XVI., A and B are two spindles. On the spindle A is fixed a small cog-wheel which gears into a larger wheel on the spindle B. If a man applies a key to the spindle A, he can bring great power to bear in moving the door, but it would be raised very slowly. So soon as he has started it he can place his key on the spindle B, and very quickly raise it to the full height. The openings in the bridges for carrying the spindle and worm-wheel, and every other working part liable to get fixed from rust, should be bushed with gun-metal. In Plate XVI. the drawings of a number of different kinds of penstocks of cast iron are given.

Working parts bushed with gun-metal.

Description of Plate XVI.

Penstock of circular sewer.

Figs. 1 and 1A are illustrations of the elevation and section of a penstock for a large circular sewer. It is fitted with a counter-weight, and compound gearing for moving and raising the door.

Dantzic penstock.

Figs. 2, 2A, 2B, and 2C are illustrations of the elevation, plan, section through door, and section through the rack and worm gearing of a cast-iron penstock, as fitted, for flushing purposes, to the mouth of the siphons which are used at Dantzic, for conveying the sewage of the town under the rivers to the pumping station.

Penstock for oval sewer.

Figs. 3, 3A, and 3B are illustrations of the plan, elevation, and section of a cast-iron penstock fitted with counter-weights, and adapted for a sewer of oval section.

Penstock for large sewer in shallow cuttings.

Figs. 4, 4A, and 4B are illustrations of the elevation, section through gearing, and section through door, showing the wedges W for closing the door. It is a cast-iron penstock adapted for large sewers in shallow cuttings, or in cases where there is not sufficient headway to introduce a penstock of the ordinary construction. The door of the penstock is divided into two parts, and on each a separate rack and worm-wheel is fixed, but only one spindle is used. The effect, therefore, when the door is raised, is for the lower portion of

the door to move over the upper portion, at the same time the whole door is raised out of the sewer, but when raised only requires half the headway to accommodate it as is required by a whole door. The door is also more quickly raised out of the way by this arrangement; but whole doors are preferable when they can be used, as this form is more complicated and liable to derangement.

## TANK SEWERS AND SEWAGE RESERVOIRS.

Cases in which sewage must be stored.

All sewers that are tide locked should be provided with the means of storing the sewage during the period the sewers cannot freely discharge their contents. In some cases, also, when it is necessary to raise the sewage of a district by artificial power, ample provision should be made for stowage, so that, in case of accidental derangement, or the temporary stoppage of the pumping machinery, from any cause, the district should not be inconvenienced by an accumulation of sewage. Moreover, in some cases, it may be found more economical to store the sewage of a district for a limited period than to have to resort to continuous pumping. In some cases, also, where it is desirable that the discharge of sewage into a tidal way should take place at a particular state of the tide, it may be necessary to store it. For example, the great outfalls of the London sewerage are so arranged, that, by means of reservoirs, the sewage is stored so as to be discharged near the point of high water. The advantage of securing the discharge near this point is that the ebbing tide carries the sewage away; and it has been calculated in this case that the reservoirs provided for impounding the sewage are equivalent in effect to the construction of twelve miles of outfall sewer. The means usually provided

Discharge into tidal streams.

# TIDE AND RAINWATER OUTLET VALVES.

Fig: 1.

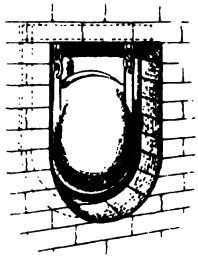


Fig: 6.

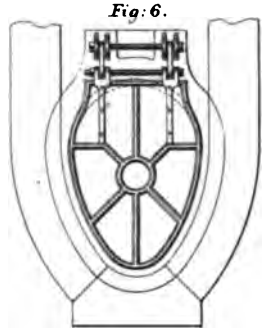


Fig: 6ª.

Fig: 7.

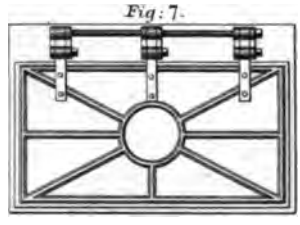


Fig: 7ª.

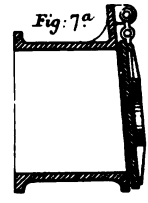


Fig: 2.

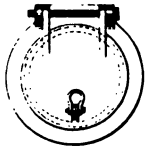


Fig: 2ª.

Fig: 3.

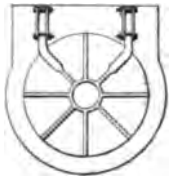


Fig: 3ª.

Fig: 4.

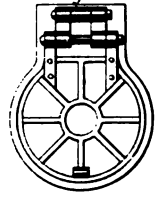


Fig: 4ª.

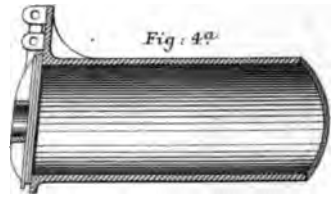


Fig: 5.

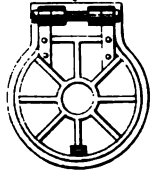


Fig: 5ª.

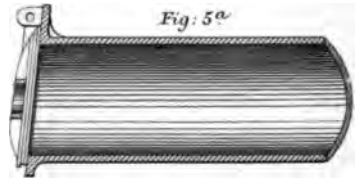


Fig: 8.

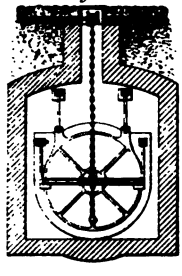


Fig: 8ª.

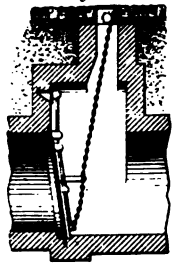
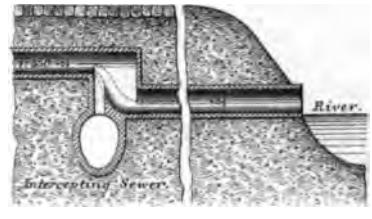


Fig: 9.

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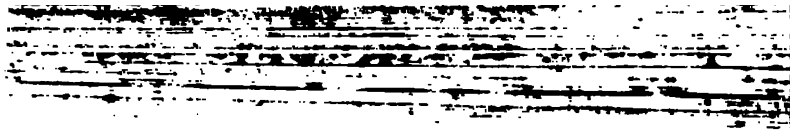

Fig: 3a

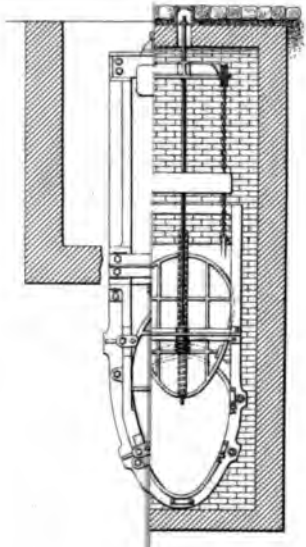

Fig: 3b

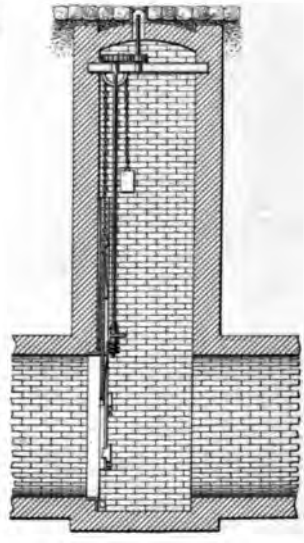

Fig: 4a
Ground line

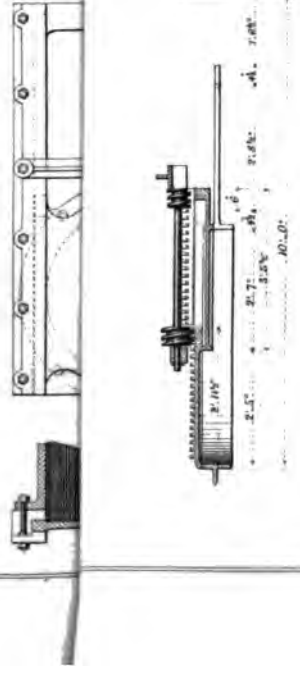

Fig: 4b

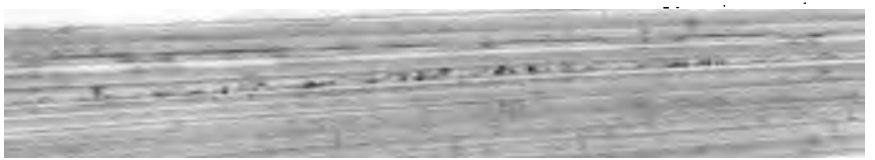

Fig: 3ª

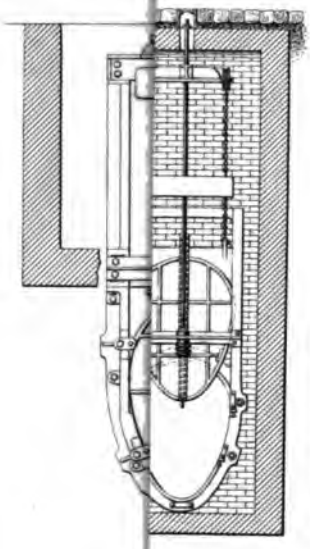

Fig: 3ᵇ

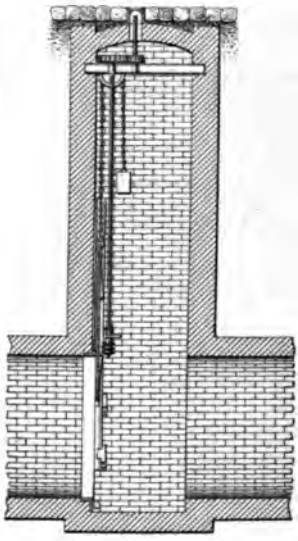

Fig: 4ª
Ground line

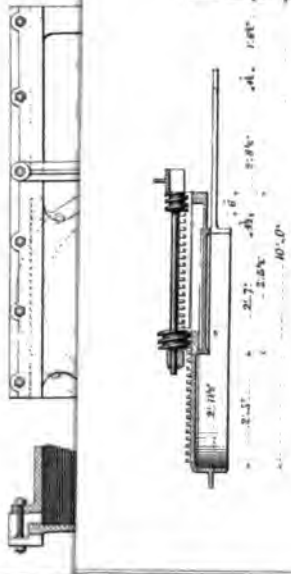

Fig: 4ᵇ

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for storing sewage are open or covered reservoirs and tank sewers. If reservoirs are used every step should be taken to prevent their becoming places for deposit. This can be done by so arranging the outlets and inlets as to be able to completely flush every part of the work. Covered reservoirs are preferable to open, and they are generally covered with brick arches springing from the side walls and piers, or from cast or wrought iron girders which span the reservoir. Tank sewers are formed by either enlarging the outfall, or some convenient branch sewer, for a sufficient length, so as to make it competent to store all the sewage required during the period the sewers are tide

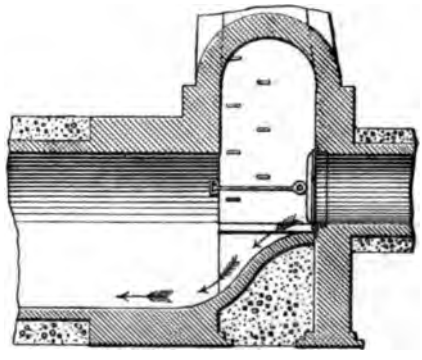
Mode of storing sewage.

Flushing reservoirs.

Construction of reservoirs.

Construction of tank sewers.

FIG. 98.



locked. Fig. 98 is a longitudinal section at the point of junction, at the head of a tank sewer, and the ordinary sewer as designed by the author for the town of Bideford. The tank sewer in this case is oval in section, 5 ft. × 3 ft. 4 in., while the outfall sewer is circular, 2 ft. 3 in. in diameter. It will be seen from the above figure that the sewer is enlarged or deepened below the ordinary level of the town sewers, and that the enlargement meets the ordinary sewer in a line of double curve, so that, when the outfall is free, the sewage flows with considerable impetus into the tank sewer, washing everything to the outfall, and thus keeping this recep-

Description of Fig. 98.

Tank sewers cleansed by flushing.

tacle free from deposit. In this case the cleansing of this tank sewer from deposit, should it arise from any cause, can be facilitated by damming back the sewage with the flushing door shown in Fig. 98, so that a large volume of sewage may be concentrated and suddenly discharged into the confined channel of the tank sewer.

In some works, when the construction of tank sewers would be more expensive and inconvenient, it may be desirable to construct reservoirs for storing the sewage,

Tank sewers preferred to reservoirs.

but for all ordinary works of sewerage the tank-sewer system is the preferable mode of storing sewage.

Volume of sewage to be stored.

The volume of sewage to be stored in the case of tide-locked sewers will entirely depend upon the period of time in which the ebb and flow of the tide occurs, and in every case careful observation must be made on this point. It will also depend upon the uncertain volume of storm water, if this water is admitted into the sewers, but in all cases where sewers are tide locked the principle of interception, as treated of at page 94, should be

Storm water should be excluded.

adopted, and as far as possible the storm waters should be excluded from the tide-locked sewers, so that but little provision need be made for the reception of an uncertain volume of sewage to be received at unknown periods. In some cases the mode described of intercepting rainfall, at page 26, and illustrated in Plate XV., Fig. 9, may be adopted with advantage, in the case of sewers that are tide locked, in order to relieve them from any large volume of rain-water, which, if admitted into the sewers when they are full, might lead to the inundation of the low-lying premises draining to the sewers.

## INVERTED SIPHONS.

In many works of sewerage, inverted siphons are required to be introduced in order to overcome the physical difficulties often met with in the course of a sewer, such, for example, as the crossing of a navigable channel, a stream, or valley which could not conveniently be bridged at the level at which the sewer must be constructed. Use of inverted siphons.

Various arrangements have been adopted, both in the form and mode of construction of inverted siphons. Experience has demonstrated that there are some forms of siphon which, in certain cases, it is preferable to adopt, as they may be termed self-cleansing. In Description of Fig. 99.

FIG. 99.

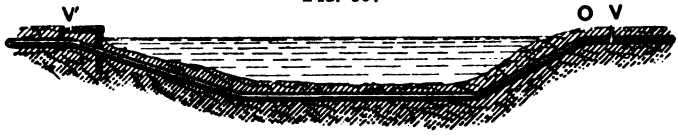


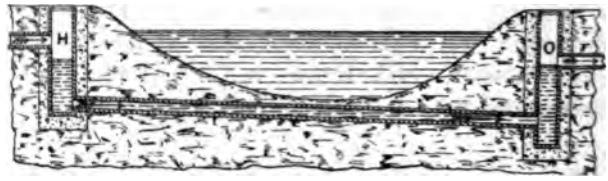

Fig. 99 is represented a siphon for conveying filtered sewage from the pumping station at Dantzic across the Kiel-Graben; it will be seen from the illustration that it follows pretty closely the outline of the bed of the river. It has two inclined planes down which everything entering the siphon has first to descend and then to ascend. It has been found that when siphons of this description have been brought into operation to convey crude sewage, and that in uncertain volume, the heavy matter carried by sewage accumulates at the lower point of the siphon S, greatly interfering with its action, so much so that it has often been found necessary to lay a copper-wire rope through siphons of this description to which a brush may be attached, for periodically removing the deposit and maintaining the siphon in working order. In Fig. 99, V represents the position of a valve for closing the rising main, so that the sewage for flush- Siphons liable to stoppage. Removal of stoppages. Flushing and ventilation of this siphon.

ing purposes can be directed through an outlet at O into the river. V′ is a valve on a 3-in. pipe, which may be opened at pleasure for the purpose of discharging air from the descending leg of the siphon. It was the knowledge of the difficulty of working a siphon of the foregoing description with crude sewage at Warwick, which led the author, in designing the outfall works of that town, when it became necessary to convey the sewage of the district under the river Avon, to adopt the form of siphon shown in Fig. 100. This siphon is 150 ft. long

Warwick siphon.

Fig. 100.

FIG. 100.




between the wells, and constructed of a single line of 24-in. cast-iron pipes. The pipes were laid in a coffer-dam in the bed of the river. The head of the pipe H is provided with a valve by which means water may be allowed to accumulate in the well and in the sewer above, which may afterwards be discharged with considerable velocity through the pipe so as to effectually flush it. The well O at the lower end of the siphon is deeper than the bottom of the siphon, and ample space is here allowed for the accumulation of any solid matter which the velocity of the current will not carry upwards to the overflow sewer. The solid matter in the lower well may be removed by periodically dredging it out, and if this work is properly attended to, no fear need be entertained as to the working of this form of siphon, as the experience of some years' constant work clearly demonstrates. In Fig. 101 is shown the form of siphon designed by the author for the sewerage works of Dantzic. It will be seen by reference to Plate I., that the sewage of Dantzic is conveyed by the sewers to the pumping

Flushing of this siphon.

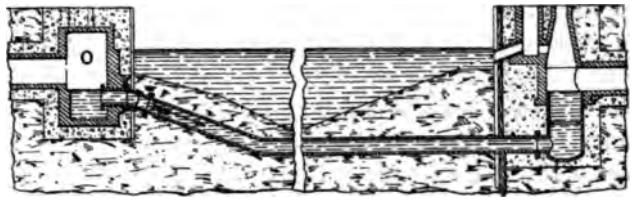
Provision for deposit.

Dantzic siphons for crude sewage.

station, which is located on an island. In order to get to this island, two navigable channels have to be

Necessity for use of siphons at Dantzic.

Fig. 101.



crossed, and in these channels it is necessary to maintain a navigable depth of 15 ft. of water, and as the foundations of the pumping station could not be carried very deep on account of the nature of the site, the only possible mode of connecting the sewer with the pumping station was by means of inverted siphons. The siphon under the Mottlau River is 80 yards long and 27 in. internal diameter; that under the Kiel-Graben is 55 yards long and 18 in. internal diameter; they are shown in Figs. 1 and 1A, Plate XVII. Both siphons are formed of wrought iron, and were each sunk in position in one piece. In carrying out the Dantzic sewerage works, inverted siphons form an essential feature in the scheme on account of the town being intersected by navigable channels, and surrounded with fortification ditches which divide the suburbs from the town proper, and over these ditches the authorities will permit no permanent works to be carried, and all works carried under the water in the fortification ditches are required to be constructed at such a depth as to maintain 6 ft. of water over them when completed. Also, on account of the main river Vistula cutting off the town from the land on which the sewage has to be distributed, no less than six large wrought-iron siphons have been introduced. One of these is laid across the Vistula, and is 160 yards in length, over which a depth of 18 ft. of water is main-

Six large siphons used at Dantzic.

Description of siphon under Vistula.

tained. This particular siphon is 22½ in. internal diameter, and weighs about 24 tons. These siphons like two others which deal with the sewage after leaving the sewage pumping station at Dantzic, are of the description shown in Fig. 99. This form was adopted for convenience, and is not so liable to stoppage as an ordinary siphon conveying crude sewage, as the sewage in this case has had strained from it, at the pumping station, all heavy matter, before being permitted to enter the siphons. Moreover, ample provision has been made so that each of the siphons of this description can be effectually flushed; as a communication is made with the channels crossed, and the pumping engines are enabled to deliver, at the low elevation of these streams, such a volume of water as will effectually flush the siphons. It must not be forgotten, in the construction of all siphons, that either by artificial flushing, or naturally, such a velocity must be created through them as will effectually remove any deposit. In the case of those under the Mottlau and Kiel-Graben at Dantzic, which convey the crude sewage to the pumping station, each siphon is fitted with a penstock at its head, of the description shown in Fig. 2, Plate XVI., so that by damming up the water, and pumping out the sewage well at the pumping station, and starting both engines to work, a velocity of 9 ft. per second could be maintained for a short time through them. Both engines, without the sewage well, would maintain a constant velocity through the largest siphon of 3 ft. per second, which is ample for insuring its being properly cleansed. Moreover, each siphon forms an inclined plane, the first portion of which is much inclined, as shown in Plate XVII., Fig. 1A, then joins with an easy curve the part less inclined. By this arrangement anything that may enter the siphon will be carried down the continuous inclined plane, and either be deposited in the catch-pit provided for its reception at the lower end of the siphon, or passed

Provision for flushing siphon.

Flushing the Mottlau and Kiel-Graben siphons.

Form of siphon, inclined plane.

onward to the pumping station. These siphons are protected at their inlet by a horizontal grating which completely fills the shaft, and placed at a level below the invert of the sewers, but above the mouth of the siphon. This grating is formed of bars of wrought iron set in a frame, about 3 in. apart, so that any large substance will lodge upon it and be prevented from passing into the siphon, the details of which are shown in Plate XVII., Fig. 2 to 15. This grating is hinged so as to be capable of being raised out of the way, and to enable the catch-pit at the mouth of the siphon to be dredged. In the Plate are shown the details of the construction of the siphons and wells as executed for conveying the sewage of Dantzic under the rivers.

Protection of mouth of siphon.

Description of Plate XVII.

Fig. 1 is a plan showing the general arrangement of the siphons under the Mottlau and Kiel-Graben, in reference to the position of the pumping station at Dantzic.

Plan of siphons.

Fig. 1A is a section through the siphons as used in crossing the Mottlau and Kiel-Graben at Dantzic, showing the general arrangement in respect to the pumping station.

Section of siphons.

Fig. 2 shows the plan of the manhole, with the sewers, siphon, and storm-water overflow, forming the inlet shaft to the Mottlau siphon.

Plan, inlet shaft.

Fig. 3 is a section on the line A B. It shows the storm-water overflow, the outfall sewers, and the horizontal grating used for the protection of the siphon.

Sections, inlet shaft.

Fig. 4 is a section through C D, looking east. It shows the mouth of the siphon with the penstock for flushing and the position of the guard grating.

Fig. 5 is a section through C D looking west.

Fig. 6 is an enlarged plan of a portion of the guard grating.

Plan of guard grating.

Fig. 7 is an enlarged section of a portion of the guard grating, on line *a b*.

Section of guard grating.

Fig. 8 is a section of guard grating on line *c d*.

Fig. 9 is the plan of the bottom of the outlet shaft.

Plan of outlet shaft.

Fig. 10 is a plan of outlet shaft at level of storm-water overflow.

Sections of outlet shaft.

Fig. 11 is a section of the outlet shaft on line A B.

Fig. 12 is a section of outlet shaft on line C D, showing the storm-water overflow.

Enlarged section of siphon.

Fig. 13 is an enlarged section showing the mode in which the siphons are constructed.

Fig. 14 is a transverse section of the siphons.

Fig. 15 is a transverse section showing the flange joints.

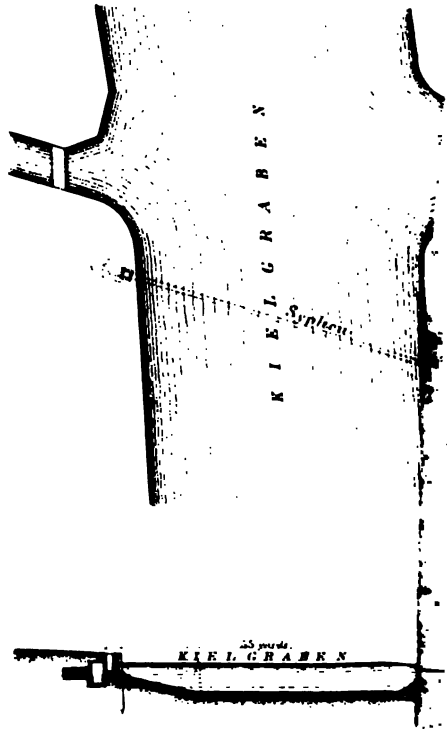
Materials used in constructing siphons.

The large siphons used in the Dantzic works are made of $\frac{3}{8}$-in. wrought-iron boiler-plate, riveted together with $\frac{3}{4}$-in. rivets having a pitch of 2 in. The rivet heads, in the lower half of the siphons, are all countersunk, as shown in Fig. 14, Plate XVII., so as to offer no impediment to the transmission of any solid matter through the siphons. The siphons were all built up in lengths of about 40 ft. Angle iron was riveted on the end of each length of pipe so as to form a flange joint. These sections were afterwards bolted together with $\frac{3}{4}$-in. bolts, the same number of bolts being used in the flanges as there were rivets encircling the pipe, and the pipes were subsequently sunk into their proper position. In cases in which there is an amount of traffic on any navigable river it is requisite to cross, the use of wrought-iron siphons, laid in one operation, will be found to be the most expeditious manner of crossing such channel. The mode adopted of laying the siphons at Dantzic was as follows:*—A trench was dredged in the bed of the river to the requisite depth to receive the siphon. It was found in excavating these trenches to be better to go a little deeper than might appear necessary, in order to guard against the effect of currents filling the trench up before the siphon was laid. The trench having been dredged, the pipe was bolted together

Most expeditious way of crossing navigable channels.

Mode of laying siphons at Dantzic.

* The work of lowering the syphon into position at Dantzic was entirely performed under the direction of Mr. Thomas Airey, the resident Engineer on the works.



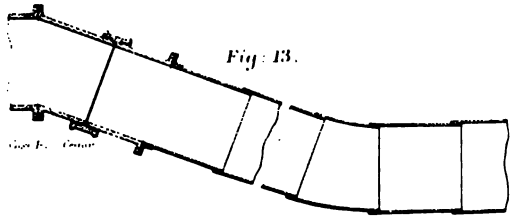



Fig: 13.

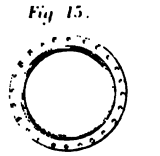
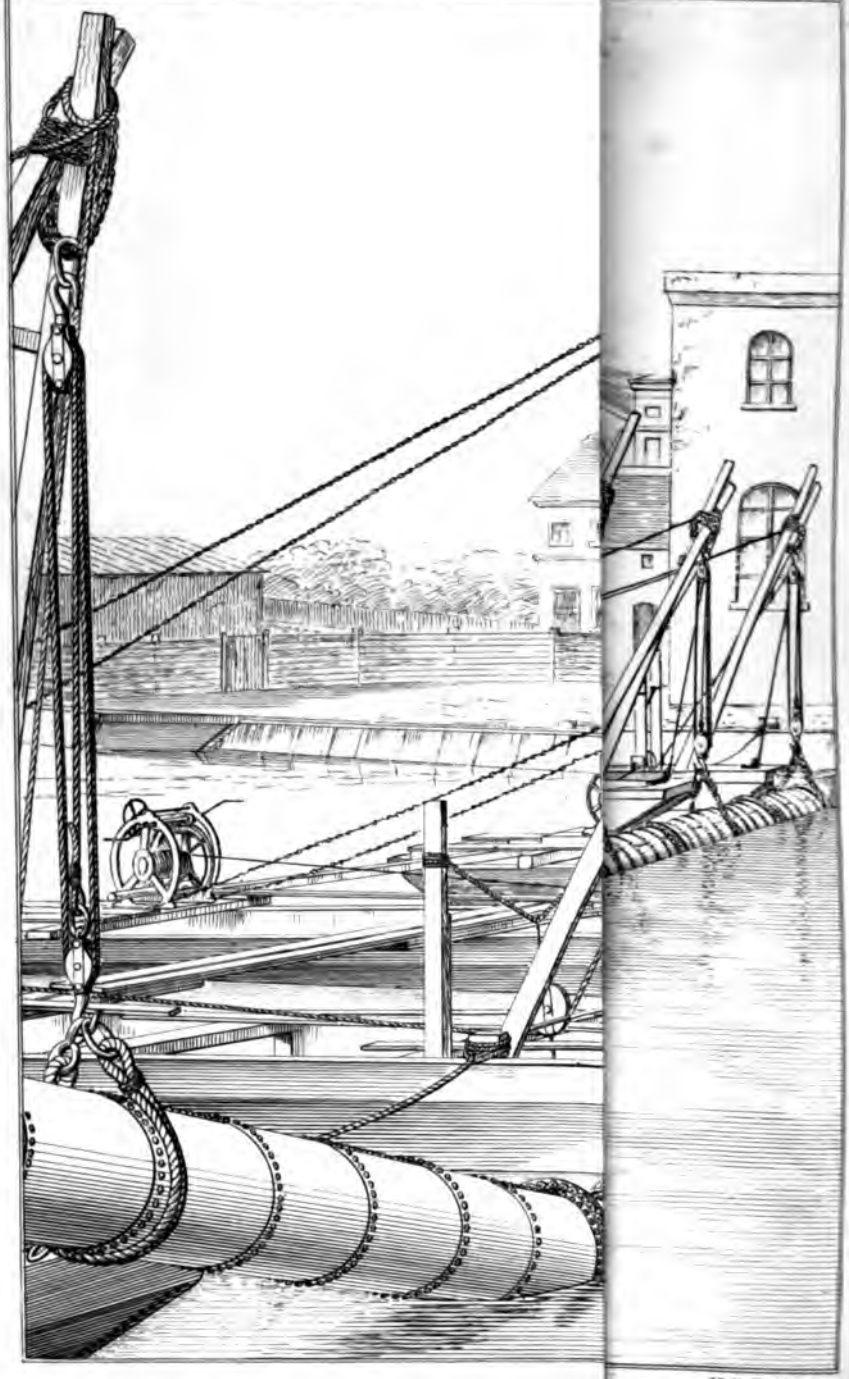


Fig 15.

Fig 14.

Fig 8

Fig 6



Kell Bros Lith.

on the side of the river, and tested under hydraulic pressure to ascertain if it was tight. All being satisfactory, a few of the joints were separated, and the siphon was floated in sections on barges to the site where they had to be laid. The barges being placed in position over the site intended for the siphon, all the sections of the siphon were bolted together, the siphons were closed at the lower end, and in the case of siphons similar to that shown in Fig. 99, at both ends. The siphons were also thoroughly coated with a mixture of pitch and linseed oil, before being fixed in position ready for sinking. The joints were made with india-rubber and afterwards run with lead and caulked. The barges used in the sinking of the siphons were each 48 ft. long by 10 ft. wide, the siphon was laid across the ends of them, and they were adjusted as to their level by means of ballast which had been taken on board. A temporary derrick was erected in each barge, together with a crab, block and falls, and used as shown in Plate XVIII., for bringing the pipe into position. So soon as the pipe was lifted by uniform working of the crabs, it was slung forward free of the barges into the water, and in this position it floated. The siphon was now steadily filled with water by the aid of a fire-engine, and gradually allowed to sink, the operation of lowering being checked by marks placed at equal distances in the fixed rope of the falls. When it had been sunk to the requisite depth it was held in position, and sand was thrown in from barges, which by the action of the water soon filled up every crevice and hollow place, and formed a firm bed for the reception of the pipe. The whole operation of laying these siphons at Dantzic was one of extreme simplicity; the work occupied but a short time, the principal labour being the supply of the necessary quantity of water to enable the siphon to sink. In sinking the large siphon across the Vistula, twelve barges with their crabs and derricks were used.

Test of siphons.

Use of barges.

Coating of siphons.

Plate XVIII.

Filling with water.

Filling of trench.

Simple operation.

In laying the siphon across the river Mottlau, the Kiel-Graben, and the fortification ditches, the bottom portion of the outlet shaft, as shown in Fig. 11, Plate XVII., was attached to the siphon and sunk with it. The success attending the laying of these siphons is such as to demonstrate the practicability of laying much longer and larger siphons should they ever be required.

Rugby siphon.

A good example of the application of an inverted siphon will be found at Rugby. Previous to the year 1866, all the sewage of the town of Rugby was allowed to flow down to the lower part of the district from whence it was pumped up upon land in the neighbourhood. The author, in the above year, designed a scheme, by which the sewage of the whole district was made to flow by gravitation on the very land upon which it had been raised by pumping for some years. This was done by conveying the sewage from the higher portion of the town, across a valley, by an inverted siphon 12 in. diameter, and 1000 yards long, to the highest portion of the irrigated land, and the sewage of the lower district was passed by a sewer under the rising ground to the lowest irrigated fields.

Flushing of Rugby siphons.

In this Rugby siphon, arrangements were made by providing an outlet at the lowest point of the valley which communicated with the low-level sewer, and the lower irrigated fields, by which means the siphon could be flushed out when required.

Siphon at Hamburg.

There is a siphon on the sewerage works at Hamburg, in which the velocity maintained is so great that, for the edification of visitors, cannon balls are transmitted through it by their own impetus and the velocity of the current.

Ventilation of siphons.

In the construction of long inverted siphons ventilation must not be omitted, especially in the descending leg of the siphon, or otherwise an accumulation of air, or gas, may greatly interfere with its discharging power. The simplest mode of ventilating siphons is by pipes carried up to such a level, that if the flow

Mode of ventilating siphons.

through the siphon is interrupted, the ventilating pipes will not overflow. Ball ventilating valves, similar to those used in lines of water pipes, are not suitable for sewage works, as the author found from experience that the frothy matter which escapes conveys solid deposit which soon blocks up the apparatus. For the purpose of calculating the discharge of a siphon pipe, it may be treated as an ordinary pipe, provided that if there are any bends the resistance offered by them must first be calculated by the formula given at page 90. The head necessary to overcome the friction of the bends being ascertained, and deducted from the actual head of water on the siphons, will give the head under which the discharge will take place, and which may be calculated from Weisbach's formula given at page 74, or if worked out into the rate of inclination by dividing the length of the siphon by the head of water on it, the velocity and discharge may be ascertained sufficiently near for all practical purposes from Tables Nos. 15 and 21.

Discharge of siphons.

## SUBSOIL DRAINAGE OF THE SITES OF TOWNS.

The results arising from the drainage of the subsoil of a town in carrying out works of sewerage have already been referred to at page 32. The advantages of complete subsoil drainage of the sites of towns appear to be so great that every effort should be made, and no expense spared, in order to secure perfect works for drying and ærating the subsoil of all urban districts. The extensive works of subsoil drainage that have been carried out in every civilized country in the interest of agriculture, show beyond doubt that both the health of animals and plants is materially benefited by works of this character. In town districts, where the soil to

Advantages of subsoil drainage.

Agricultural drainage.

Necessity for subsoil drainage.

some extent naturally becomes polluted by the absorption of gaseous impurities from the air, or by the admittance by percolation of decomposing matter from the surface, it is absolutely necessary, in order to render the soil capable of performing its function of oxidizing and neutralizing the elements of decomposition which are brought into contact with it, that works of sub-drainage should be prosecuted. It is now well known that the abundant admission of air into a soil enables that soil to exert the most powerful chemical influence upon all organic compounds, so great indeed as to be capable of purifying the crudest sewage. The effect of drainage upon the soil is to promote porosity, and the effect of porosity is to make the soil dryer, warmer, and less capable of conveying extremes of temperature. It is also well known that a soil perfectly saturated with water, which can only part with its water by evaporation, is rendered cold and unwholesome as a site for human dwellings, for all impurities that enter the soil accumulate. Soils which are naturally porous, from which rain rapidly disappears, are known to be the healthiest situations for the sites of houses. In this case, the action of the soil oxidizes all organic impurities, the resulting product is wasted away by the rain, and the soil remains sweet and wholesome. The advantages of site appear to have been known from the early ages of antiquity. Vitruvius in his works lays down special instructions for selecting the sites of towns and hospitals, mainly regarding the quality of porosity and the perfection of drainage; the absence of a water-logged soil being looked upon as the best situation for the location of buildings. It has been clearly shown from experiments that the effect of drainage upon ordinary agricultural land is to render it less capable of conveying extremes of temperature. Undrained fields are sooner affected by the lower temperature of winter, or by sudden showers of sleet and snow, than fields of the

Effect of æration of soil.

Healthy soils.

Vitruvius.

Influence of change of temperature.

same class that are drained. In summer the effects of the admission of water or rainfall upon a soil which is drained, and which circulates freely through the soil, are highly beneficial. It has already been pointed out that drainage works promote porosity; so rain, falling on the surface of a town and percolating through the soil, rapidly carries with it all those deleterious compounds which in the presence of air have been neutralized, and a healthy circulation takes place; the soil is, as it were, washed by every shower, and retains its virgin purity. In what way the works of subsoil drainage can be carried out in a town, with the greatest advantage, is a matter which has received some considerable degree of attention at various times. Formerly, when sewers were constructed with a view to carry off the surface and subsoil water, it was customary to construct the inverts of the sewer so porous as to readily admit water from the subsoil; the sewers, being constructed in brickwork, had their inverts laid dry. It cannot be overlooked that where a system of modern sewers is designed to convey away all the refuse of the town, the effect of constructing the inverts of such sewers pervious, is, that at certain periods of the year the sewage will escape into the subsoil and poison the subsoil water of the district; therefore it is necessary that wherever subsoil drainage works are undertaken, they should be so designed and constructed, if it is intended to keep the subsoil water free from contamination, that it shall be impossible for matters to escape from the sewers so as to pollute the subsoil water. Various plans have been devised for effecting the subsoil drainage of a town. It has been proposed to construct the sewers of two parts, the upper to convey away sewage, and the lower to be pervious, to convey subsoil water, as shown in Fig. 102; but in practice it is found that it is almost impossible to make the joints of the sewers so tight but that at times they will leak, and

Rain washes a drained soil.

Pervious sewers.

Subsoil water must not be contaminated.

Description of Fig. 102.

Brookes' system.

in consequence sewage gravitates to the subsoil drains and pollutes the water. A modification of this plan has lately been patented by Messrs. Brookes and Sons, of Huddersfield, and is illustrated in Fig. 103. In this case, subsoil drains, D, of earthenware, are laid in the sewer trench, and these drains are so shaped as to serve for the foundation of the sewer. On these subsoil drains, rests (R) are placed to receive the sewer-pipe, which is carried above the subsoil drain. It is contended that by this mode of executing a sewer in bad and wet ground, the joints of the sewer may be properly made in cement, so as to render it water-tight; but still this system has the objection that if leakage does take place from the sewer, the water in the subsoil drain must become polluted. Moreover, this plan of carrying the pipes on rests causes every pipe to act like a girder, which, under some circumstances, may lead to their failure in the work. In carrying out the sewage works of Dantzic, Mr. Wiebe and the author introduced a plan of subsoil drainage which meets all the difficulties, and secures all the advantages which are required in carrying out works of this character. The method adopted is shown in Figs. 104 and 105. The sewer proper S, whether constructed of brickwork or earthenware pipes, was first laid in the trench and covered over with a layer of clay puddle C, which was well and carefully rammed into position. In some cases, over this clay, several feet in depth of the trench were filled in with selected

Description of Fig. 103.

FIG. 102.

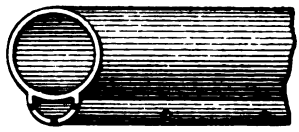
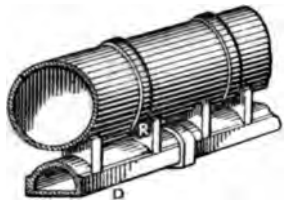


FIG. 103.




Subsoil drainage works, Dantzic.

Description of Fig. 104.

gravel, shown by G, Fig. 104, which is perfectly pervious, and upon this gravel the ordinary materials excavated, E, were placed; the arrangements for the

Fig. 104.

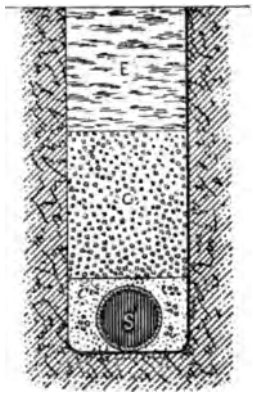
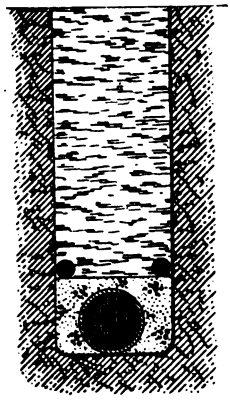



Fig. 105.



discharge of the subsoil water were so managed that every lateral line of sewer is provided with a free discharge into the river. In other cases the method shown in Fig. 105 was adopted after the insertion of the sewer and its covering of clay; two lines of ordinary agricultural land drains were laid on each side of the trench, so as to communicate directly with the surface-water streams of the district. Subsoil drainage may be carried out in most places in the way delineated in Fig. 105, care being taken that the sewers are rendered impervious, so as to prevent the escape of sewage, porous drains being laid immediately above them; the subsoil water may be conveyed to any convenient point, and air may be admitted freely into the subsoil, while the expense of the work is trifling compared with the advantages to be gained. In some situations, such as in very low-lying and swampy districts, it may be necessary to admit the subsoil water into the sewer, in order that the soil may be effectually drained by having its

Description of Fig. 105.

Expense of subsoil drainage trifling compared with advantages.

Admittance of subsoil water into sewers.

surplus water pumped out of it. In such situations there is no fear of the subsoil water becoming polluted from the sewers, as there would always be a constant flow into the sewers, and not from the sewers outwards.

## HOUSE DRAINAGE.

Crowning point of system.

The work of house drainage is the crowning point of a system of sewers. Upon the care and skill bestowed in carrying out this portion of the sanitary requirements of a district in a great measure will depend the ultimate success of the works in a sanitary point of view. It cannot be overlooked that imperfect sanitary works in connection with the houses in which we reside will result in the malarious influence of the sewers and drains being brought to bear directly upon their occupants. As a rule the works of house drainage are carelessly and thoughtlessly carried out, and often inflict untold injury on the luckless occupants of the house in which they are executed. It should be said that the train of evils, which often follows the improper execution of house-drainage works, is not due, generally speaking, to the character of the workmanship, but to faults in principle in the arrangements adopted.

Work of house drainage.

We will now consider what are the requirements necessary to be fulfilled in carrying out house drainage, and how best this work can be performed. House drains are intended to carry away from houses all liquid refuse, waste surplus water, and fæcal matter; and, while performing this duty, they should be so designed and constructed as to prevent the entrance of sewer gas into the house. The rate of flow through house drains is liable to considerable fluctuation, and the temperature varies greatly; and these two causes, as already pointed out, of necessity require that ample

Fluctuation in flow.

ventilation for the drains shall be provided, and the reasons for, and the way in which this work should be performed have already been fully considered under the head of ventilation of house drains, page 266. It has also been pointed out at page 50 that small drains, such as 4 in., 6 in., and 9 in., the sizes generally used for connecting houses with the sewers, should not have a less rate of velocity of flow through them than 3 feet per second, in order to render them self-cleansing. This would give, by reference to Table No. 7, page 56, the least inclination for a 4-in. drain, 1 in 92; for a 6-in., 1 in 137; and for 9-in., 1 in 206; but in order to produce this velocity in drains of this calibre, they would require to run half full, so that a 4-in. drain would require to be provided with water at the rate of 7·85 cube feet per minute; a 6-in. drain with 17·66 cube feet per minute; and a 9-in. drain with 39·76 cube feet per minnte. Now it will be seen from these figures that there are but few cases in which the requisite volume of water could be provided for keeping the house drains properly cleansed if laid so flat as the above rate of inclination, therefore, in order still to make the house drains self-cleansing, they must, as a general rule, have a greater rate of inclination than that absolutely requisite to render them self-cleansing when provided with a sufficient body of water. In cases where a greater fall than given above cannot be secured, all house drains should be provided with special means of being flushed. The means usually provided for flushing house drains consist of a tank similar to the manhole, Fig. 54, page 185, which may be filled up with water; or, in other cases, the ordinary sewage may be made to act as shown in Fig. 55, page 187. The mode of forming the junction between the sewers and drains, and between drains and their branches, has already been considered at page 174, and it is therefore unnecessary here to further allude to this part of the subject. All house drains

Size of house drains.

Velocity of flow.

Inclination and discharge of house drains.

Greater fall must be given than theoretically requisite.

Flushing of house drains.

Laying of house drains.

should be laid in virgin soil; if constructed in made ground, a good foundation should be secured by laying the sewer in a broad base of concrete. Great care must also be exercised in the course taken by house drains. They should, as far as possible, be laid outside the house, and not under it; but if the carrying of a drain under a house is unavoidable, every precaution must be taken in the laying and jointing, so as to prevent the escape either of sewage, or sewer gas, from the drains. It must not be forgotten that when a house is built and the site drained, that the soil dries and becomes porous; at the same time, if clay is used in the jointing of the pipes (which is commonly the case), it is liable to dry and shrink. Mr. W. H. Wheeler, M.I.C.E., states that "a roll of wet clay 1 foot in length" was "found to shrink in length about $\frac{1}{2}$ an inch" in drying. In cases where the passage of drains under houses is unavoidable, they should be jointed with gaskin and cement or asphalte, or they should be embedded in Portland cement concrete of extra fine quality.

Laid outside house.

Jointing the pipes.

In considering the proper position of house drains, it is well to call attention to a frequent cause of failure of drains in connection with new buildings, and that is, if a drain is passed through the external walls of the building, and the building subsides or settles down, the drain invariably is injured either by being broken off, or the joints of the sewer pipe open, so as to lead to the ready escape of sewer gas into the building. The remedy for this is to leave ample space at the points where walls are pierced, so that they may settle without injuring the drain. The materials used in the construction of house drains, and the interior fittings of a house, require careful selection, and constant inspection to ascertain that the works are sound. House drains are usually constructed of glazed stoneware socket pipes. The soil-pipes for water-closets, the pipes for baths, lavatories, and sinks, are constructed of iron,

Effect of settlement in drains.

Selection of materials.

Lead pipes.

lead, and zinc. Lead is one of the best materials that can be used for soil-pipes; but the pipes should be drawn or cast, and not soldered together, as is often the case, for with soldered pipes the two metals have unequal rates of contraction and expansion, and often rend at the seams. Moreover, a galvanic action is often set up, which is destructive to the pipe. Lead is injuriously acted upon by sewer gas and lime, and not unfrequently a pipe gets honeycombed by the action of lime falling into the pipes when they are first placed in position, which lodges in a bend, and contact with water and fæcal matter soon perforates the pipe. In some cases fæcal matter will injuriously affect ordinary commercial lead. On account of its composite character, galvanic action is set up which rapidly destroys the pipe; care therefore should be taken in the selection of lead pipes, that they are made of pure lead, and not of composition. Iron pipes are used in some cases as soil-pipes, but they are not so good as lead, as the interior of the pipe is liable to become coated from oxidation, and fæcal matter adheres to the rough surface. Zinc ought not under any circumstances to be used for conveying fæcal matter, as it is rapidly destroyed under its chemical influence. Earthenware pipes may be used for the soil-pipes, and may be built into the wall, as already pointed out at page 272. In house drainage the sinks in the scullery and elsewhere are often the cause of much mischief, the traps provided for excluding sewer gas having such a small amount of seal that in practice they prove inoperative. Moreover, there are so many contingencies which injuriously affect traps, and which have already been referred to at page 278, that it has been found necessary to cut off all direct communication between the sink and the house drain. The best and most effectual way of performing this operation is shown in Fig. 106, where S represents the sink; T the trap, which is merely used to prevent currents of air entering the house; P the pipe for conveying the waste water

Iron pipes.

Zinc pipes.

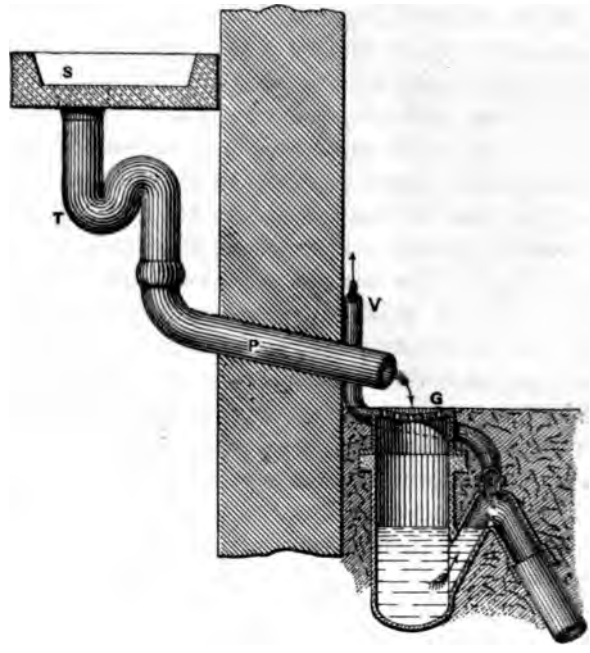
Earthenware pipes.

Drainage of sinks.

Description of Fig. 106.

from the sink through the external wall and discharging it on the surface of the gulley G; V is the ventilating pipe for the gully, which may be carried to any

Fig. 106.



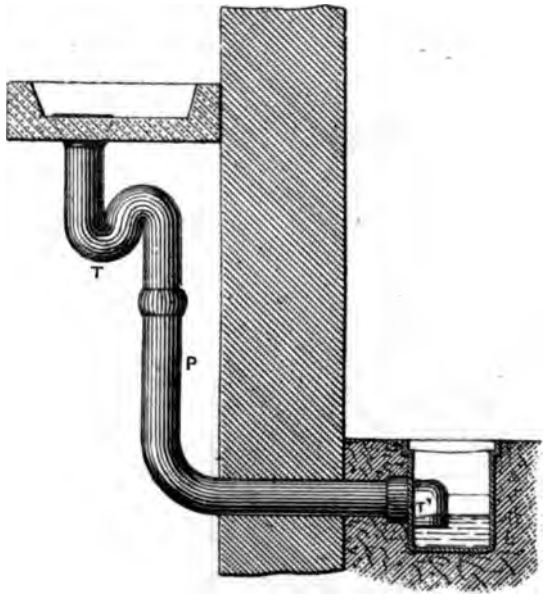

convenient point; and D is the pipe leading to the drain. When this plan cannot well be adopted, on account of the unsightliness of the open grating, the gully may be sunk in a shaft covered with a grating for protection, and still the pipe may be made to discharge upon it, or in some cases the pipe may be connected with a Mansergh's trap, as shown in Fig. 107.

Description of Fig. 107.

Mansergh's trap has already been described at page 292, and an illustration is given in Plate XIV., Fig. 14. This arrangement is not so good as the former; for if the pipe P is of great length, it is apt to become coated with grease and other matters; the air coming

in contact with these matters would be fouled, and as every discharge through the pipe must displace a por-

FIG. 107.



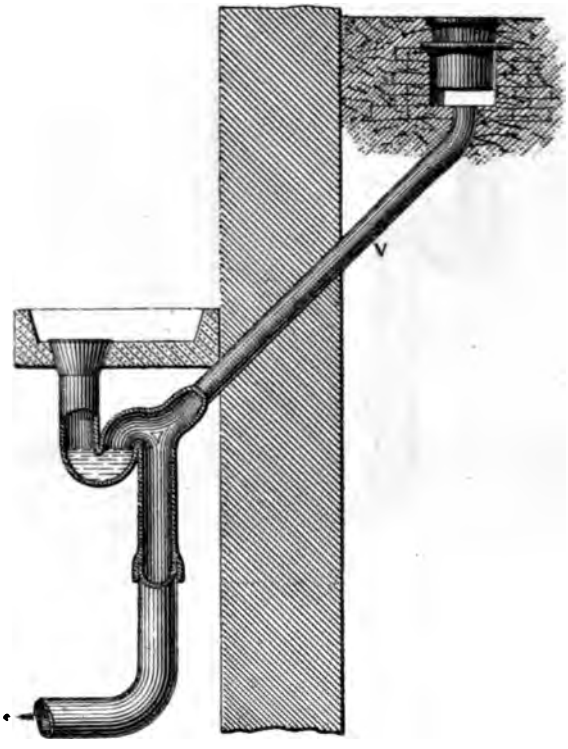

tion of this foul air, it would ordinarily escape into the house unless the trap T has a greater amount of seal than the trap T'. In Fig. 108 is represented another mode of dealing with a sink. This is an illustration of the mode adopted by the author in ventilating the drains of the sinks in Blenheim Palace. In this case all the drains were constructed in the interior of the palace, and the ground outside is at a considerable elevation above the sinks; a ventilator pipe V has therefore been taken from the trap under the sink, and carried some distance outside the palace, where it is made to terminate under a charcoal ventilator of the description shown in Fig. 82, page 259. It is only necessary to add that the gullies in areas or yards near houses should all be ventilated either by pipes or by

Description of Fig. 108.

Blenheim Palace.

other special modes pointed out under the head of ventilation of sewers and drains. The general arrangement

Fig. 108.




of the drains and ventilating pipes of a house are shown in Plate XI. The mode of dealing with the drainage and of ventilating the water-closets is shown in Fig. 109.

Ventilation of water-closets.

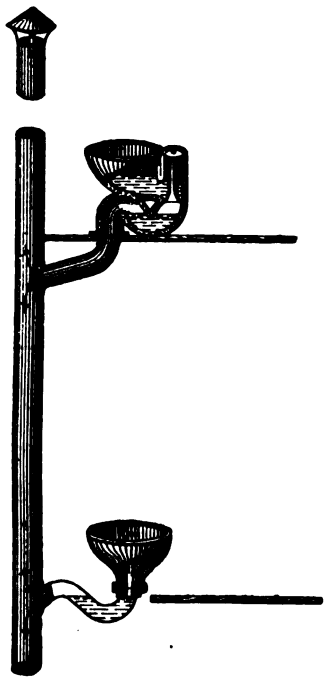
Description of Fig. 109.

It consists simply in carrying up the soil-pipe to the roof or some other convenient point, care being taken that no windows, house ventilators, or the flue of a chimney shall be near the point of termination, as at times there are in-currents into the house at these points. If it is necessary to carry the soil-pipe up to the ridge, the pipes for this purpose may either be

carried inside or outside the roof; but in all cases it is better and safer to place both the soil-pipe and all other pipes in connection with the drains outside the house, protecting them with proper casings and packings from frost. The same provisions should be made for the ventilation of urinals as for water-closets. The general details of the construction of water-closets and urinals will be hereafter considered. The overflows from cisterns communicating directly with drains are the frequent cause of much mischief, and, moreover, often lead to the waste of much water. It is quite clear that if the water-fittings of a cistern are in perfect working order, no water can overflow by the overflow-pipe, which is usually provided and sealed with a water-trap. Now, as the water in the trap is seldom renewed, except by the overflow from the cistern, the trap soon gets dry, and leaves the pipe in direct communication with the drain; and the gaseous impurities being absorbed very readily by the water, it is not unfrequently contaminated and rendered deleterious to the health of the persons using it. The overflows and waste-pipes of all cisterns should either be treated like a sink, as shown in Fig. 110, in which P is the wash-out and overflow-pipe of a cistern brought down the external wall and made to discharge on the top of an open gully G. This

Pipes better outside of house.

Fig. 109.



Urinals.

Overflow for cistern.

Description of Fig. 110.

pipe may be trapped at the top O with an Antill's trap, described at page 291, and illustrated in Plate XIV.,

Fig. 110.

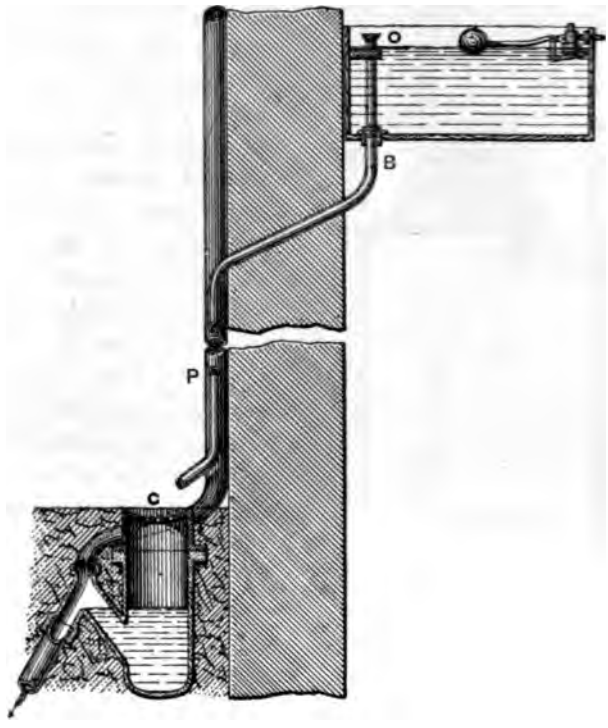



Fig. 5, or it may have an ordinary siphon trap at B. These traps are merely intended to prevent currents of air entering the house by the overflow-pipe. In some cases the overflow from the cistern may be treated as shown in Fig. 111. The overflow-pipe in this case is simply carried through the external wall of the house. As the overflows from cisterns are not liable to be fouled* from the discharge which passes through them, they may be conveniently trapped at the bottom with Mansergh's trap, Plate XIV., Fig. 14. The pipes for lavatories may be treated in a manner analogous to the

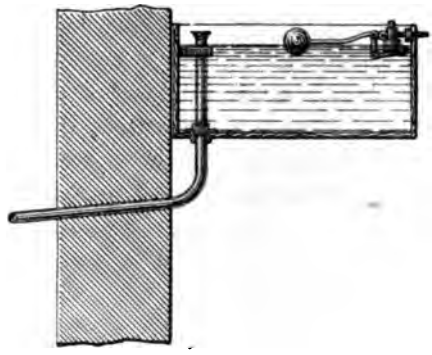
Description of Fig. 111.

Mansergh's trap used for trapping overflow of cistern.

* *Vide* page 320.

method pointed out for sinks; or in some cases, when located in the upper floor of a house, the discharge-pipe may be carried through the outside wall of the Lavatories.

FIG. 111.



house, and there be made to discharge into the open head of a pipe, discharging upon a trapped gully at the ground level. The waste water from baths should also be conveyed like that from sinks and lavatories, already described. The safes or pans provided in connection with closets* and baths are often a source of danger, for unless the drains from them are constantly provided with water they become untrapped. The best plan of dealing with the uncertain quantity of water that finds its way into these safes is to treat the pipes draining them the same as the pipes from a lavatory, and carrying it directly outside the house. In some cases the safes of baths may be effectually kept drained by the drain provided for taking away the waste water; for if the top of this pipe terminates below the level of the safe, and is kept open, the waste water from the bath being conveyed into it by a distinct pipe, it will thus serve the double purpose of draining both the bath and its safe, and the volume of water contributed by the

Baths.

Safes.

* The trap of the safe of a water-closet should be supplied with water by a small pipe communicating with the supply pipe to the closet, so that, every time the closet is used a small quantity of water would pass into the trap.

Rain-water pipes.

bath will keep the trap supplied. Rain-water pipes are best not connected directly with the drains, but cut off, as shown in the case of the cistern overflow, Fig. 110. On no account ought rain-water pipes to be used as ventilating pipes of the house drains, for reasons already stated at page 230. It is only necessary to add that the

Drainage of cellars.

drainage of cellars and low-lying places, the level of which is but slightly above the level of the drains, and which in time of storm are liable to be inundated, that the trap for draining them ought to be provided with a valve similar to that described at page 288, and illustrated in Plate XIII., Fig. 22. In many cases it will be found that if the house drain is brought up to the external wall of the house, it will effectually drain the subsoil, and no opening need be made communicating directly between the drains and the lower floors. In this case the head of the drain should be closed against the escape of sewage in time of flood, or otherwise, where waste water will drain away, sewage may, by back pressure, enter, and the consequence may be that the whole of the subsoil under the house may be permeated with sewage matter, to the great detriment of the health of its inhabitants.

## WATER-CLOSETS.

Water-closet, ancient device.

The water-closet is a very ancient device for receiving and carrying away in water fæcal matter. Its use has been traced to all nations that had arrived at a

Ewbank's 'Hydraulics.'

certain degree of refinement. In Ewbank's 'Hydraulics' it is stated that water-closets "are an ancient and probably Asiatic device." The summer chamber of Eglon,

Ancient water-closets.

King of Moab (Judges iii. 20–25) is supposed to have been one. They were introduced into Rome during the Republic, and are noticed by several ancient writers.

Those constructed in the Palace of the Cæsars were adorned with marbles, arabesque, and mosaics. At the back of one still extant there is a cistern, the water of which is distributed by cocks to different seats. The pipe and basin of another have been discovered near the theatre at Pompeii, where it still remains. Heliogabalus concealed himself in one, whence he was dragged by his soldiers and slain. Water-closets seem to have been always used in the East, and for reasons which Tavernier and other Oriental travellers have assigned. Numbers are erected near the mosques and temples. A similar custom prevailed in old Rome, Constantinople, Smyrna, and probably all ancient cities. In the city of Fez, "round about the mosques, are 150 common houses of ease, each furnished with a cock and marble cistern, which scoureth and keepeth all neat and clean, as if these places were intended for some sweeter employment." (Ogilby's 'Africa,' 1670, p. 88.) In his 'Relation of the Seraglio,' Tavernier describes a gallery in which were several water-closets. "Every seat (he observes) has a little cock." He mentions others in which the openings were covered by a plate, which by means of a spring "turned one way or the other at the falling of the least weight upon it." Sir John Harrington is said to have introduced water-closets into England in Elizabeth's reign, and some writers have erroneously ascribed their invention to him. They are described in the great French work on Art and Manufactures by M. Roubo, who says, they were long used in France before being known in England. Those which he has figured are, however, on the ancient plan, without traps, and such are still to be found in Oriental cities." In the buried cities of Herculaneum and Pompeii an apparatus very similar to the modern water-closet has been discovered. Although water-closets in some shape or other have been in use in this country about three hundred years, it was not until the latter end of the last century that they became gene-

Introduction of water-closets into England.

First patent water-closet.

rally introduced. The first recorded patent in connection with water-closets in this country was taken out by Alexander Cumming, 11th November, 1775. This was followed by another patent in 1777, taken out by Samuel Prosser, and the following year Joseph Bramah secured a patent for a valve-closet, which has been very extensively used throughout the country, and is still in much request. Since that period several hundred patents have been taken out for water-closets, or matters in direct connection with them. The descriptions of water-closets now in use are very numerous; but all closets resolve themselves into two classes, water-closets with valves and traps, and water-closets with simple traps. The requirements of a good water-closet are, that it shall be inodorous, shall work efficiently with a minimum quantity of water, and shall be simple in construction and not liable to get out of order. There can be no doubt that many water-closets which are now in general use are extremely defective in the principle of construction, and when introduced into a house, instead of being a comfort and luxury, are a positive nuisance, and often endanger the health of its inmates. Most of the complaints which have been raised against the water-carriage system have been directed almost solely against the water-closet, as being the source of nuisance when introduced within a house. These complaints have in many instances been well founded, as there cannot be a shadow of doubt as to the nuisance caused by many descriptions of closets; but the remedy is not to abandon the water-carriage system, but to correct the defects in the form of closet which have given rise to these complaints. A good water-closet is the only appliance fit to be used within a house, for by it all matters are at once conveyed away and cease to have the power of producing evil so far as our houses are concerned; it is not so, however, with those systems that conserve fæcal deposits within or in close proximity to our dwellings, as there is always

Bramah's valve-closet.

Water-closets of two classes.

Requirements of good closet.

Many defective closets in use.

Water-closet the best sanitary appliance.

Fig: 1.

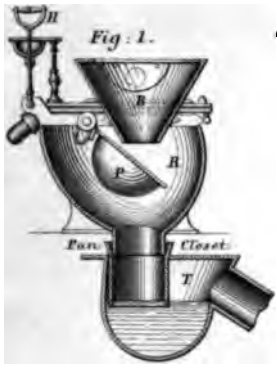



Fig: 3.

Fig 24.

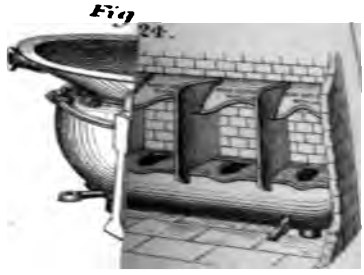


Fig: 5

25.

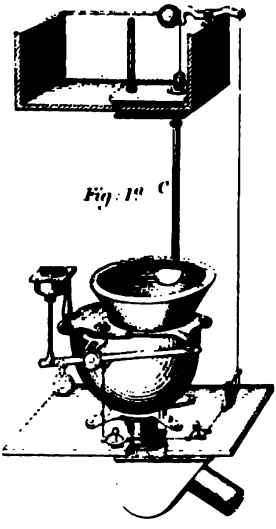
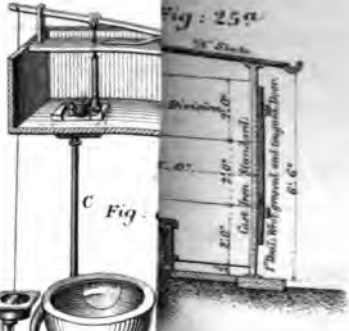


Fig: 1ª C



Fig: 25ª



C Fig:

Fig: 25b

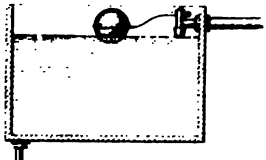


Fig: 2.

Fig: 7.

danger in storing a dangerous article, however carefully we may tend and guard against its evil effects.

By far the greatest number of water-closets in operation in the best houses of this country are expensive and cumbrous appliances, and cannot be introduced within a house without creating a nuisance. They are generally known as pan-closets, and a section of one is delineated in Plate XIX., Fig. 1. It consists of four distinct parts: 1st, the basin B, which is usually made of earthenware; 2nd, the pan P, which in the drawing is shown to be removed from its place at the bottom of the basin by the partial raising of the handle H; 3rd, the receiver R, in which the pan works; and 4th, T, the ordinary D trap. When ready for use, the pan P retains water, so that as the bottom of the basin B dips into it a trap is formed, and the fæcal matter is deposited in the water retained in this pan. When the handle H is raised to the full extent, the fæcal matter and water are thrown from the pan on to the sides of the receiver, from thence they fall down, or are washed down by the water flowing through the opening at the bottom of the basin into the trap T, and thence to the drain. The effect of this action of the closet is that the receiver R gets completely coated with fæcal matter, so much so that it is the practice in many establishments to have the closets removed once a year and have the deposit burnt out; but this cannot remedy, but only palliate, the nuisance, as the continual plastering of the interior walls of the receiver with fæcal matter in the presence of moisture causes decomposition to take place, and noisome gases are generated, which accumulate in the receiver between the two traps; and every fresh discharge from the closet displaces an amount of this foul vapour, which passes at once through the open basin into the apartment, and thence into the house, and no amount of ventilation of the receiver will remedy this defect, which is inherent in this particular form of closet and in a less degree in some other forms of closet con-

Defects of pan-closet.

Nuisance of pan closet.

Defect of valve-closet.

structed on this principle. The valve-closet (Plate XIX., Fig. 6) invented by Bramah is somewhat less objectionable than the pan-closet already described, for instead of having a receiver provided large enough for the large pan to work, this chamber in the valve-closet is reduced in size in order to admit only the working of a small valve; but this form of closet still retains the objectionable feature already pointed out, of an evaporative area coated with fæcal matter, and a space to collect the gases evolved by decomposition, and its direct passage into the apartment every time the water-closet is used. Owing to the nuisance arising from these particular forms of closet, it has been proposed to construct all water-closets in a separate building from the house, communicating by passages so arranged with doors, and provided with ventilation, as to prevent any escape of noisome vapour entering the house. In other cases double doors are used in connection with the entrance to the apartment in which the water-closet is placed, but such measures are only palliative; the true remedy is the introduction of a form of water-closet free from the defects pointed out. It will be found in practice that some of the simplest and cheapest water-closets are the best; in fact all those closets consisting of a simple basin and trap, usually called the Hopper closet, if provided with ample water for flushing, the closet can be used without causing any nuisance, as there is no space for noisome gas to accumulate and no exposed area plastered with fæcal deposit to generate foul gas; and if the closet is provided with ample ventilation* in the way already pointed out, or by carrying up the soil-pipe to some convenient point, no gases can pass back through the trap to cause any mischief. It should be here stated that many of the Hopper closets in use, owing to defects in the construction of the trap and from the inadequacy of the flush of water, do not clear themselves at every discharge of the closet; the con-

Proposal to construct water-closets in separate buildings.

Simplest and cheapest closets best.

Defects of Hopper closet.

* *Vide* page 322.

sequence is that fæcal matter is left in the trap, and its exposure often gives off a bad odour. Those who require a still more perfect closet than the simple basin and trap will find Mr. George Jennings' closet (Plate XIX., Figs. 14 and 14A) a perfect sanitary appliance. It consists of a basin and trap made in one piece of earthenware, but instead of the small quantity of water usually occupying the trap of a Hopper closet, in this case a hollow plug P is used to dam up the water in the basin. The consequence is that the fæcal matter is at once dropped into a large volume of water, and to a certain extent it is immediately deodorized, as those peculiar organic odours given off by fresh fæcal matter are prevented from escaping, and when the handle H which lifts the plug is raised, everything in the basin is suddenly discharged into the trap below, and so into the drain. The hollow plug also serves as an overflow if the basin fills too high. It may be here observed that the apartment of every water-closet ought to have external openings to the air. Air openings should invariably be formed near the ceiling for the discharge of foul air, and fresh air may be admitted at the floor-level.

Jennings' closet.

Advantages of large volume of water.

Ventilation of water-closet apartment.

The arrangement for the supply of water to the water-closets of a house is one of extreme importance in a sanitary point of view; but how often do we find that the water supply of a district is intermittent, and that a single cistern only is provided for storing the water for all domestic and dietetic purposes, and for the supply of the water-closets and urinals. Frequently the apparatus for actuating the delivery of water to the water-closet is fixed in the only cistern, from which a pipe is carried to the closet, and wires are carried from the closet to the cistern for actuating the valves, as, for example, in Plate XIX., Figs. 1A 6, and 17. The effect of this arrangement is that the pipe C, which conveys the water to the closet when empty, is supplied with air of very impure quality, or that which is drawn from the basin of the water-closet,

Supply of water to water-closets.

Cistern arrangement often defective.

and this air at the next discharge is carried up to the cistern, from which water for culinary and other purposes is drawn. When it is generally known how prone water is to attract impurities, such a state of things will not be tolerated; for the least that can be said of the æration of the water of the cistern from such a source is, that water so treated cannot, like Cæsar's wife, be beyond suspicion. In a sanitary point of view, the placing of the valves for regulating the supply of water close to the basin of the closet is a great improvement on the older plan already referred to. Such an arrangement of valve is shown in Plate XIX., Figs. 2, 4, and 16; but with this arrangement, unfortunately, there is no control over waste, which is often a serious matter with water proprietors; for if the handle of the closet fitted with this arrangement is propped up, a continuous flow of water would pass through the closet into the sewers. This arrangement of valves is, however, not a good sanitary arrangement, for, in cases where water is laid direct from the water-mains to the closet, unless provision is made in every house service to prevent the back flow through the service pipes, should the valve of the closet be opened during a period when the water is being shut off the district, a flow of air would enter by the valve, and in consequence the water-mains would become filled with air of an objectionable character.* To guard against the evils of the valve arrangement, and to prevent the waste of water, a great number of very ingenious devices have been introduced. The simplest arrangement for the prevention of waste, and as a good sanitary device to prevent the fouling of the general water supply of a house or district, consists in introducing a separate cistern for each water-closet. It may be fixed on brackets over the seat, and should derive its water supply from a store cistern, as shown in Plate XI., from which drawing the relative posi-

Position of valve close to closet-basin.

No control over waste of water.

Æration of water-mains from water-closets.

Water-waste and sanitary cisterns.

Plate XI.

* This æration of the water of towns in which there is an intermittent supply is constantly going on. Hence the necessity for a constant supply.

tion of these cisterns with the store cistern will at once be seen. In Plate XIX., Figs. 19, 20, and 21, the form of cistern now commonly adopted for the supply of water to water-closets is shown. The great point with regard to these cisterns is that the outlet-pipe to the closet should be of good size, say not less than 1¼ inch diameter, in order to supply water quickly to the closet; for it is found by experience that a small volume of water flowing quickly and at once through a water-closet is more effective than ten times the same quantity supplied in mere dribblets. Water is usually distributed in the pan either by a flushing rim formed round the upper edge of the basin, or by a fan fixed against the back of the basin. In some of the commoner closets simple apertures are made through which the water is discharged into the pan. The form of basin should be so arranged as to have a receding back, so as to present no exposed area for the reception of fæcal matter; and the water supply should be directed not so much to wash the sides of the basin as to wash away through the trap all fæcal matter deposited in it. The quantity of water required for effectually flushing a closet varies much with the description of closet and other circumstances. As a rule, one gallon of water may be considered an ample supply for each flush of a good closet. The position of a water-closet ought to be so arranged as to guard against the injurious action of frost. The pipe for conveying water should be placed in the interior wall, and every provision should be made for protecting it by suitable non-conducting clothing; and in some exposed cases, where the prevention of freezing cannot be obviated, a proper valve arrangement should be supplied by which the pipes may be emptied of water in time of frost. A very good water-waste preventive cistern, not liable to derangement in frost, as there are no valves to freeze, is made by Mr. Hall, of Leeds. It consists simply of a tilting bucket actuated by the handle of the closet. Special

Water-waste cisterns.

Advantages of large outlets.

Distribution of water.

Form of basin.

Quantity of water required.

Position of water-closet.

Protection from freezing.

Hall's water-waste cistern.

Outside closets.

care needs to be taken with outside closets to prevent both the traps and the supply pipes from freezing. In many cases where the sewers of a district are laid sufficiently deep, the whole closet may be formed with advantage below the ground-line; for if placed sufficiently deep and approached by a flight of steps and secured with a good door, no fear need be entertained of the effects of frost. A little common salt placed in the trap will prevent its freezing, and at the same time the salt constitutes an excellent deodorizer.

Closets may be fixed below the ground-line.

Deodorization of water-closets.

In some cases it is the fashion to deodorize water-closets with special apparatus, such as that of Dr. M. A. Gardiner Brown, and supplied by the Chloralum Company, which consists of a vessel containing liquid disinfectants, communicating by means of a small pipe with the supply pipe to the closet, so arranged that a portion of the disinfectant fluid flows out each time the closet is used.* As a general rule, the disinfection of water-closets is not required, unless in periods of epidemic or illness within a house, or in the case of a hospital, when steps ought, as a matter of duty to common humanity, to be taken so that the fæcal matter and other discharges from patients are properly disinfected before being passed into the sewers of a town.

Disinfection of matters passed into sewers.

Outside closets without special water supply.

In some districts it is not considered necessary to lay on water to the outside closets, the pouring down of the ordinary liquid refuse into the basin of the closet being found sufficient for all purposes of keeping them clear. In these closets no difficulty can arise from the effects of frost, as there is always sufficient warm water used for domestic purposes to keep the closet from being frozen or to unfreeze it should it get frozen.

Materials used to construct closets.

The materials used in the construction of water-closets are enamelled iron, earthenware, china, and glass. The basin and traps should all be thoroughly well glazed. Enamelled iron will not wear like earthenware, as the enamel is apt to get chipped and cracked, when the

* Baker's apparatus for the disinfection of water-closets effects the same object, and is sold by "The Patented Disinfector Company."

water gets in contact with the iron oxidation takes place, which soon completes the destruction of the closet. With the common Hopper closet it is usual to limit the size of the openings at the bottom of the basin to about 2½ in. diameter in order to prevent the entrance of matters into the drains they are not intended to convey. Water-closets inside houses should, when convenient, have the soil-pipe kept outside the house. Various modes have been adopted for actuating the working parts of a closet so as to render them self-acting. Without requiring any particular action on the part of the person using the appliance, a very common mode is to attach the working parts to the seat, which is hinged, as shown in Plate XIX., Fig. 17. In other cases a portion of the floor may be hinged. In either case the weight of the person using the closet is made the motive power for actuating the valves which regulate the supply of water. In other cases the door of the apartment in opening or closing is made to perform the necessary operation. In some water-closets the valve arrangements are entirely out of the control of the person using the closet; as, for example, in latrines and trough closets, which are in use in some districts, and are emptied once a day by a scavenger opening the valve, which is under his control. Latrines and trough closets are very generally used in many public establishments, such as schools, workhouses, manufactories, barracks, &c. Illustrations of closets of this description are shown in Plate XIX., Figs. 23, 24, and 25. Trough closets are fitted with an overflow and plug for discharge. The bottom of the trough or pipe inclines to the end at which the discharge plug is placed. They may be filled with water by a regulator ball-valve fixed in a division of the trough, or by a valve actuated by the handle of the discharge apparatus, or from a stand pipe or tap, but can only discharge their contents by the raising of the plug, which is usually locked up and kept under proper control. A very good arrangement and improvement on the trough

Size of opening into drains.

Pipes kept outside houses.

Self-acting closets.

Water-closets not under control of persons using them.

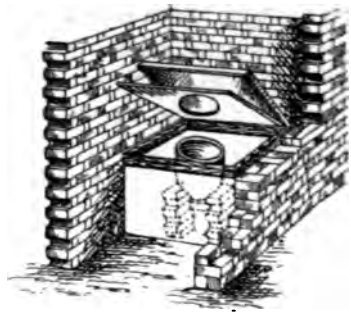
Trough closets.

Latrines.

closet is that shown in Plate XIX., Fig. 25. It is the representation of a range of closets or latrines as designed and executed by Mr. George Jennings. In cases in which there are no housemaids' sinks for conveniently discharging slops it is often the practice to make use of the water-closet as a receptacle for them, and in some cases already noticed, when water is not laid on to the closet, the slops are invariably poured down them. A water-closet within the house under these circumstances should be fitted with a safe* to catch any slops that may be spilled, and the seat of the closet intended for the reception of slop should be hinged so as to turn up out of the way when slops are discharged, as shown in Fig. 112.

Water-closets receiving slops provided with moveable seat.

FIG. 112.



Description of Plate XIX.

In Plate XIX. is shown a variety of forms of water-closets which have been adopted at various times.

Pan-closet.

Figs. 1 and 1A represent the section and elevation of the ordinary pan-closet. This closet has already been fully described, and is not recommended for use. It was originally introduced to supersede the valve closet invented by Bramah.

Pan-closet with regulator.

Fig. 2 is a pan-closet similar to the last, but the water supply is regulated by a valve near the closet, and this valve is kept from closing too quickly by an arrangement attached to the lever called Underhay's bellows.

* *Vide* page 325.

Underhay's regulator.

Fig. 3 is an enlarged view of Underhay's bellows. It consists simply of a cylinder with piston. Air can enter the cylinder quickly when the handle of the water-closet is raised, but it can only escape except by a small opening, so that the lever with its weight will descend slowly, and consequently the valve can close without any shock, and water flows sufficiently long after the pan is closed for it to be filled up with water.

Eskholme's regulator.

Fig. 4 represents a pan-closet with valve arrangement. The valve in this case is kept from closing quickly by means of Eskholme's pneumatic regulator.

Pan-closet.

Fig. 5 is a representation of a pan-closet of another kind, the receiver in this case being rather smaller than in the former.

Valve-closet.

Fig. 6 is an illustration of Bramah's valve-closet in its modern form. It differs from the pan-closet in the size of the receiver, which is smaller, and presenting a diminished area of evaporative surface. These closets constantly get out of order, and do not hold water, as a piece of paper or other material easily prevents the valve closing, and consequently the basin loses its water.

Conical Hopper closet.

Fig. 7 is a common conical closet or simple Hopper closet with siphon trap, the trap and basin being formed of one piece of earthenware. This form of closet had its origin, no doubt, from the fact that water-closets of this description were ordinarily constructed of the cast-off moulds used in sugar manufactories.

Conical closet and trap.

Fig. 8 represents another form of closet. The basin and trap are constructed separately. It is a form that was at one period extensively used. An improvement on this form of closet was made by Mr. Phillips, which consisted in making the back of the closet straight, so as not to be so likely to collect fæcal deposit.

Hopper closet receding back.

Fig. 9 represents an earthenware closet in one piece. This is a good form if the receding back as well as the front and sides are provided with a flushing rim. It was originally introduced by Mr. Geo. Jennings.

Mr. J. Roe's closet with ventilation.

Fig. 10 represents a conical closet invented by Mr. John Roe. In this form of closet the flushing rim is carried all round the basin, so that a good flush may be insured. V is a pipe inserted for the purpose of ventilation. The conical shape of the basin of this closet renders it very liable to collect fæcal deposit, when it cannot be efficiently washed and flushed except by the expenditure of a large quantity of water. This invention affords the first practical example of the proper way of ventilating the drains of a closet.

Closet with bye flushing pipe.

Fig. 11 represents a conical closet with flushing rim. It is also supplied with a pipe B for effectually flushing out the siphon trap at the bottom of the basin. This form of closet with bye flushing pipe was introduced to remedy the defect which, as already referred to,* attends the Hopper closet, that is, the cleansing of the trap after the use of the closet. In practice it is found that in closets with basins of this description, so shaped that the back part projects, fæcal matter will soil the walls of the basin, but if the back is made to recede, as in the closet Plate XIX., Fig. 9, the fæcal matter will not strike the basin, and if accidentally does touch it is readily washed off by the flush of water.

Patten's basin.

Fig. 12 is an illustration of Patten's basin. It consists of an ordinary Hopper and trap, with the addition of a screen S, the object of which is to hide from view the matter deposited in the trap. The author's experience in respect to this form of closet is that fresh fæcal matter is often deposited on the screen, and not being covered with water, unpleasant effluvium is given off while the closet is being used, or until the matter is washed away or covered with water.

German closet.

Fig. 13 is a section of a water-closet of German pattern. It consists of a tilting basin, which forms a sort of movable basin within an ordinary water-closet, an arrangement very similar to the tilting basin now commonly used in lavatories. The movable basin B is attached to the front part of the seat, which is hinged

* *Vide* page 330.

at H. To empty the basin the front of the seat at A must be raised, when the basin tilts and discharges into the trap below; at the same time water is admitted by a valve arrangement through the pipe W for washing out the basin and trap.

Jennings and Lovegrove's closet.

Figs. 14 and 14A represent two sections of Messrs. Jennings and Lovegrove's water-closet. It is without doubt the most perfect closet introduced up to the present time. It is manufactured in one piece of earthenware, and may be fitted to any water-waste preventive or sanitary cistern. It consists of a basin and trap below. P in Fig. 14 is a hollow plug, which dams up the water in the basin, forming, when the basin is full, a second trap T'. The handle H is raised as in Fig. 14A; the hollow plug rises with it, and the contents of the basin are rapidly discharged into the drains. Ventilation is provided for these closets by a pipe screwed into a hole drilled into the body of the closet behind the lower trap.

Improved Hopper basin.

Fig. 15 is the representation of a water-closet as designed by the author. It is an improvement on the ordinary Hopper closet. The object of this closet is to get a large body of water in the basin B, in order that the fæcal discharge may at once be completely deodorized. The lifting of the hollow plug H causes the water-line to fall to the level of the water in the common Hopper closet; at the same time the volume of water accumulated in the basin, and the subsequent flush, causes everything to be carried away through the trap T; and if the closet is not clean it will be at once seen, whereas in all closets in which the traps are hidden from view it can never be known for certain if the fæcal matter has been discharged or remains in the trap to give off noisome vapours. The ventilation of the drain of this closet is effected by a pipe inserted at V, and by an arrangement of levers at L it may be fitted with water-waste preventive or any valve arrangement for the supply of water.

Water-fittings of Hopper closet.

Fig. 16 shows the arrangement of connecting an ordinary Hopper closet, by means of a lever-valve, with the water service. It should be observed that with this form of water-fitting no control can be exercised as to the amount of water that may be consumed or wasted through the closet; moreover it is objectionable for the reasons that have already been considered.

Patten's water-waste preventor.

Fig. 17 is an illustration of Patten's water-waste preventor fitted in a cistern. If the cistern to which this apparatus is fitted is the only source of supply for a house, the arrangement cannot be justified; if, on the other hand, the cistern is used solely for the water supply of closets and urinals it may not always prove satisfactory as a water-waste preventor. G represents the basin and trap; C, the pipe communicating with the cistern; B, a service box formed within the cistern; A and E are valves actuated by the lever *d* by the wire or chain *e*, attached to the hinged seat F of the closet, O is the overflow pipe for cistern. It also forms the ventilator for the service box. The action may be explained as follows:—The weight of a person sitting on the closet draws down the wire *e*, which raises the valve A, and the water fills the service box. When the person rises from the seat the valve A closes, and the valve E opens, which allows the contents of the service box to be discharged. It is quite clear, with this arrangement, that if only a sufficient weight were placed on the seat as only partly to lift the valve A, the valve E at the same time would be lifted, and a continuous flow of water would take place.

Clark's water-waste arrangement.

Fig. 18 represents Mr. Clark's (of Reading) mode of fitting up a water-closet to prevent waste. In this case the weight of a person sitting on the seat of the closet is used, through an arrangement of rods and levers, to liberate a ball-valve *e*, *b* being the lever which ordinarily holds the lever of the ball-valve; *c* is a small valve which closes the mouth of the pipe *g* when the rod *b* is raised upwards. The action is as follows:—

When a person sits on the seat *a*, by a lever arrangement under the seat the rod *b* moves upwards and liberates the ball-valve *e*, at the same time the valve *c* falls into its seat. Water now fills the cistern *d*, from which, when full, the supply is cut off by the ball-valve floating on the water, and so soon as the person rises from the seat the weight of the rods causes the valve *c* to open, at the same time fixing the ball-valve that no further water can enter the cistern, the contents of which are discharged into the basin of the water-closet.

Single water-waste preventive cisterns.

Fig. 19 is a representation of a small cistern applicable to a water-closet; it is a water-waste preventor. The cistern is filled by means of a valve actuated by the ball B, which, so soon as it is filled, cuts off the supply. The action is as follows:—If the lever L is pulled down, the lever L′ rises, and in rising the weight W, which is slotted and passes over the arm of the ball-valve, first raises and then holds it The slack chain C is then tightened, and by the continued depression of the lever the valve V is raised, and the contents of the cistern are discharged into the water-closet, and no more water can enter the cistern D until the valve V is returned, and then the ball-valve is liberated. This apparatus is a sure preventive against waste of water. In this arrangement only one charge is stored in the cistern D for the supply of the closet.

Double water-waste preventive cistern.

Fig. 20 represents a double water-waste preventor. The cistern D in this case may hold several charges for the water-closet, but only one charge can pass at a time to the closet. The action is as follows:—The weight W at the end of the lever keeps the valve V raised so that water may pass into the lower chamber of the cistern R. Now if the lever L is depressed it first lowers the valve V so as to prevent any more water entering this chamber R; it then lifts the valve V′ and the contents of the lower chamber are discharged into the water-closet, and no more water can be passed until the lever L resumes the position shown in the drawings.

Cistern with after-flow.

Fig. 21 represents a water-waste preventor cistern similar to the last, with the addition of the chamber R', through which the water flows from the chamber R, the object of this arrangement being that after the handle of the water-closet is lowered, water will still pass out of the chamber R', so as to fill the pan of a pan-closet after the valve V' is raised.

Trough-closet.

Fig. 22 is the section of a trough-closet fitted with a basin B, of earthenware, and discharging into a trough G, below the level of the floor of the apartment. The trough may be arranged so as to discharge its contents either into a drain or into a liquid manure cart.

Macfarlane's trough-closet.

Fig. 23 is a view of a Macfarlane's trough water-closet arranged for a single individual. The closet is shown to be supplied with water by means of a ball-valve fitted in a division at one end of the trough, and at the other the arrangement for discharging and the overflow pipe are shown. The plug in this case forms a trapped overflow for the closet.

Range of trough-closets.

Fig. 24 is a view of a range of seats on a trough-closet, applicable for a barracks and such like places. Over the seat a hood is fitted for the purpose of preventing a person standing on the seat to use it. In some continental towns the water-closets at the railway stations are all fitted with backs sloping outwards at a considerable angle, so as to render it impossible to use the closet except by a person sitting down upon the seat. Such measures as these are sometimes necessary to preserve the cleanliness of the seat in some particular cases; but as a general rule they are not required, at least not in this country.

Mode of preventing standin on seat.

Jennings' latrines.

Figs. 25, 25A, and 25B, represent plan, transverse section, and sectional elevation of the latrine manufactured by Mr. George Jennings. It may consist of any number of basins of earthenware, which are fitted into a cast-iron pipe which joins them altogether. A hollow plug P, shown in Fig. 25B, both regulates the height to which the water and other matter may rise,

and serves the purpose of discharging the contents of every basin. Each basin is supplied with water, so that they can all be washed out. For schools and in some other cases the plug for discharging is out of the control of the persons using the closets, as it can only be raised by a lever. The general arrangement of this latrine is preferable in a sanitary point of view to the trough arrangement before referred to.

Latrines preferable to troughs.

## URINALS.

In all districts of an urban character, public urinals should be constructed as a matter of convenience, and as a preventive of nuisance being committed in places out of proper sanitary control. Urinals are also required to be constructed in houses, manufactories, and other places, where proper consideration and cleanliness is a matter of vital sanitary importance. A urinal not properly attended to soon becomes a frightful nuisance, as urine very rapidly undergoes decomposition, and gives off a disgusting odour; and when in this state it has the power of rapidly turning fresh urine into the same state, hence the necessity of thoroughly cleansing and washing every part of a urinal. Urine, as a manure, is by far the most valuable part of town sewage. As compared with the solid fæcal discharges, the value of urine is as 6 to 1, therefore every effort should be made to secure the urine produced in a district for agricultural purposes. In some manufacturing towns urine is regularly bought and collected in lant carts for use in the fulling of woollen cloths.

Public urinals should be provided.

Effects of decomposing urine.

A great variety of forms of urinals has been introduced at different times, and now urinal basins are articles of common manufacture by all firms manufacturing sanitary goods. In Plate XX. is shown a variety of urinals now in very general use. They

Variety of form.

usually consist of simple basins fixed against a wall, or of stalls made for a person to enter, or of a basin fixed within a stall, so as to screen the person using the urinal from observation. Urinal basins are usually made of glazed earthenware, and sometimes of common stoneware. Stall urinals are made of iron lined with slate or plate-glass, rough plate-glass, slate, and enamelled slate. The water supply in most public urinals is constant, but in private urinals it is only supplied as required, either by the person opening a valve, or by a treadle arrangement, by which the person standing upon a grating actuates the discharge of the flushing water, or sometimes by an arrangement actuated by the door of the apartment in which the urinal is fixed. Water-waste preventive cisterns may be fitted and applied to urinals in a manner similar to that already referred to under the head of water-closets. In the distribution of water to a urinal, care must be taken that every part of the urinal is properly washed; and it is, moreover, desirable that a supply of water should be introduced below the feet, an open grating being provided on which the person using the urinal can stand, with a water supply below the grating to wash away urine that may have dripped on to the floor, or, in the case of children using the urinal, may not have reached the urinal basin. The volume of water required varies greatly with the description of urinal. In those cases in which the urine is discharged into a trough, and the water merely used as a dilutant to assist in washing away the urine, the volume of water required is small; but in cases in which stalls are used, and a constant supply is provided,* this supply is often equal to half-a-gallon per minute per stall. The water in basin urinals is distributed by a flushing rim, and in stall urinals either from a perforated pipe or a spreader made specially for the purpose. In stall urinals the width of the stall

Materials.

Water supply.

Water required.

Distribution of water.

Width of stalls.

* The volume of water consumed by an urinal, having intermittent discharge, is equal to about half-a-gallon for each time it is used.

Fig: 1.

Fig: 2.

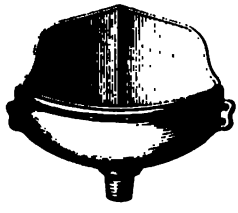


Fig: 3.

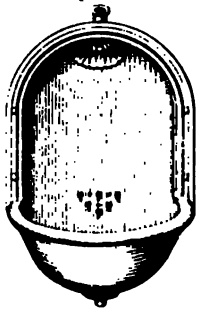


Fig: 4.

Fig: 5.

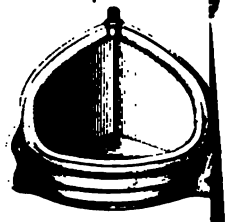
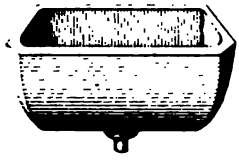


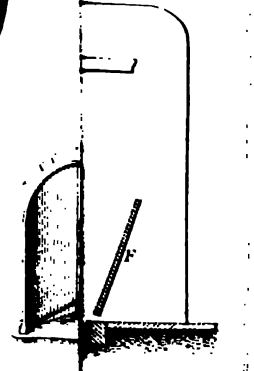
Fig: 6.

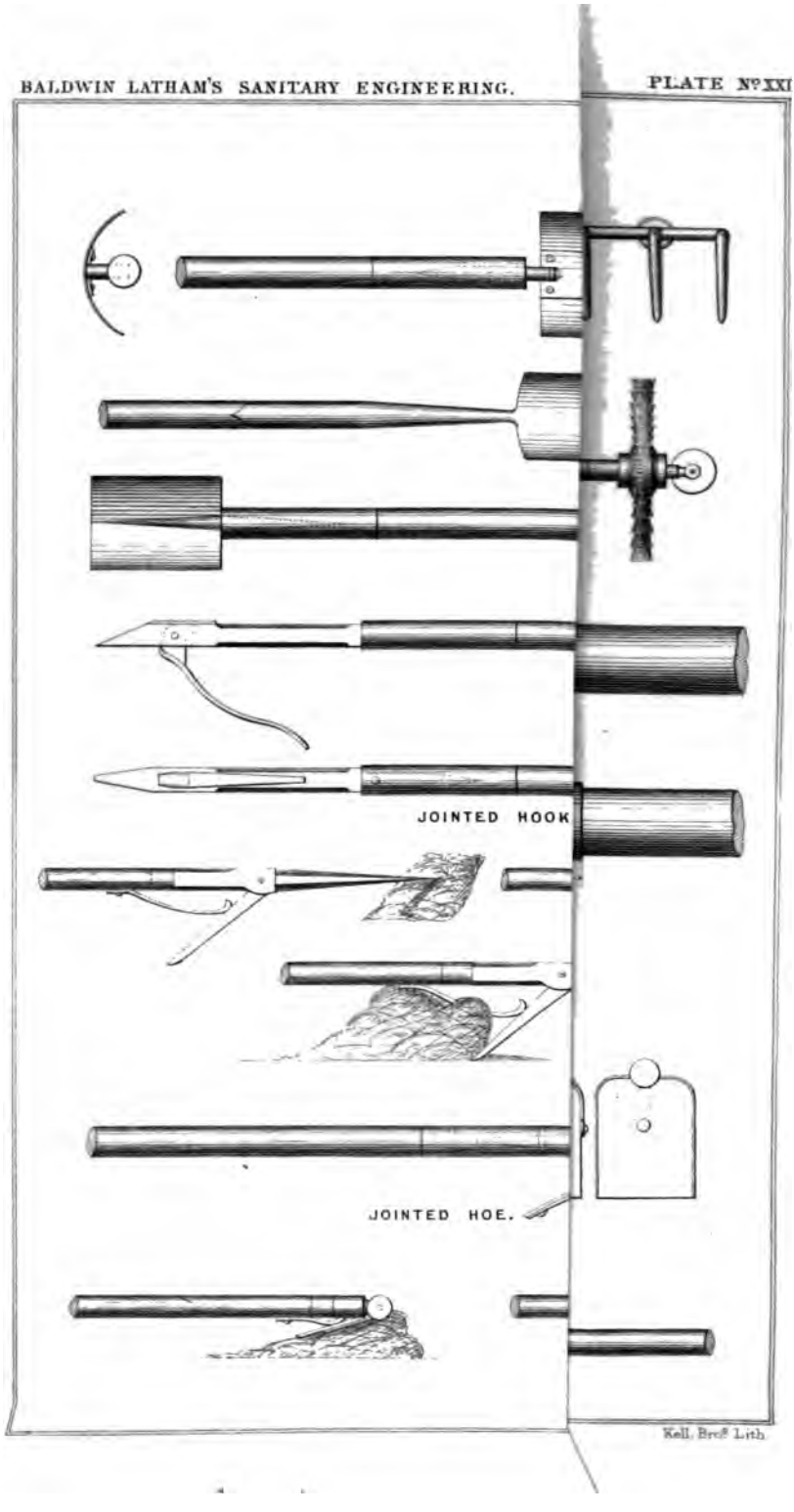
Fig: 7.

Fig: 8.

Fig: 9.








Kell. Bros Lith.

ries from 1 ft. 8 in. to 2 ft. 6 in. As a general rule, talls of less than 2 feet are very cramped, and lead o a nuisance outside the urinal, as some persons will not enter a narrow stall.

Trapping and ventilation.

Urinals are generally trapped with the ordinary siphon trap, and provision should be made for the ventilation of the drains communicating with a urinal, especially in cases in which they are constructed inside houses. The best mode of ventilating urinals is to carry up the drain-pipe in the same way as the soil-pipe of a water-closet is treated. In many continental cities the provision of public urinals has had a fair share of consideration, and urinals are placed in the most prominent situations. The base of a lamp column is often converted into a one-person urinal, with hardly sufficient protection for decency sake. All public urinals ought to be so constructed that while they are readily accessible they are sufficiently screened from public view, and on entering them privacy can be secured. The same observations apply to public latrines, which unfortunately, in the towns of this country, are rarely ever supplied. Accommodation of this class as a rule is only provided at the various railway stations or hotels, and thither the roving public has to wander when requiring accommodation of this character.

Lamp-column urinals.

Privacy.

Latrines.

Description of Plate XX.

In Plate XX. are shown various forms of urinals adapted for public and private purposes.

Bedford urinal.

Fig. 1 represents an earthenware urinal called the Bedford urinal. It is fitted with flushing rim all round, and is intended to be fitted into the angle formed by the walls of a building.

Angular urinal.

Fig. 2 is an angular earthenware urinal with flushing arrangement at front. This form of urinal is also used without a supply of water, but such a mode of using urinals cannot be recommended, as a urinal without water speedily becomes a great nuisance.

Cradle urinal.

Fig. 3 is a urinal constructed of earthenware, provided with both flushing rim and fan. From its shape it is called the cradle urinal.

Flat-back urinal.

Fig. 4 is a very similar urinal to the last, except that the back is flat.

Fig. 5 is a very similar urinal to Fig. 1, differing only in the proportion of its parts.

Lipped urinal.

Fig. 6 is a form of urinal now very generally adopted. It is called the lipped urinal, that is, it is drawn out very narrow in front so that the projecting lip may pass between the legs of the person using it, and so prevent dripping on the floor. This form of urinal was originally introduced by Mr. George Jennings.

Fig. 7 is what is termed a projecting urinal, with flushing rim all round.

Common angular urinal.

Fig. 8 is a common angular urinal of a form made in stoneware.

Fig. 9 is an oblong urinal made either of earthenware or stoneware.

Antill's trap.

Figs. 10 and 10A represent an elevation and sectional elevation of a urinal fitted with an Antill's trap-drain at A. B is a sealed opening provided for getting at the trap in case of stoppage.

Cradle and stall.

Fig. 11 shows the arrangement by which a cradle basin is fitted within the stall of a urinal, the water supply being actuated by the person standing on the grating which forms a treadle and opens the valve as shown. This arrangement of treadle grating may also be made to actuate the apparatus connected with a water-waste preventive cistern.

Stall urinal.

Fig. 12 is an illustration of a simple stall urinal as constructed by Messrs. Macfarlane in iron.

Fig. 13 is an illustration of a stall urinal constructed in iron by Messrs. Macfarlane, and is applicable for a street.

Jenning's urinal.

Figs. 14, 14A, and 14B represent plan, section below the ground line, and elevation of a urinal as originally introduced by Mr. G. Jennings. In this case the urine enters a central basin, in which is discharged a constant supply of water, and from which both water and urine pass by a trapped overflow plug. The basin can at

any time be emptied by drawing the plug. The urinal is surrounded by an open iron grating, and any water dropping on the grating passes away to the drains by the arrangement shown in Fig. 14A. These urinals are very largely used in the metropolis and elsewhere. The divisions between the stalls are made of slate, the rest of the structure is of iron.

Trough urinal.

Fig. 15 is a section of a very old form of urinal, consisting simply of a cast-iron trough which passes through a range of stalls. This form has been superseded by the form shown in Fig. 16.

Stall urinal.

Figs. 16 and 16A represent the elevation and section of a stall urinal, as very generally adopted at railway stations. The fender-piece F prevents the splashing which takes place in some other forms of urinal when used. This fender-piece should not reach the floor, but leave a space below for drainage, so that every part of the urinal may occasionally be washed down, and any water and urine dripping on to the floor would find its way to the gutter.

Fig. 17 is a representation of a section of a urinal designed by the author. An open grating is provided for the feet, and below this grating is an inclined floor, which is washed down by water from a distributing pipe. The urinal may have a continuous or intermittent action for the flow of water. In the arrangement of the apparatus for distributing water every part of the urinal should be washed. In many urinals the divisions between the stalls never get washed, and consequently such urinals are never entirely free from smell. In this urinal the pipes for distributing the water are returned some distance round the divisions of the stalls.

In St. Petersburgh and other northern towns the water supply of urinals is cut off in the winter, and instead thereof fresh sawdust is used in the basins, through which the urine percolates to the drains.

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